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Final Report on the Project

PLEISTOCENE CHRONOLOGY

OF THE

GREAT LAKES REGION

By Jack L. Hough

Office of Naval Research
Contract No. N6ori-07133
Project NR-018-122

University of Illinois
Urbana, Illinois

January 31, 1953

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J. L. Hough

Principal Investigator

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INTRODUCTION

OBJECTIVES OF THE RESEARCH

The objective of the research, as originally stated, was to work out as complete a time scale as possible for the later part of the Pleistocene glacial and post-glacial time for known events in the Great Lakes region. It was assumed that the major events were already known, and that their sequence of occurrence was correctly known. The objective was to be attained by counting varves or annual sediment layers associated with the glacial drift. Varve deposits in several places in the region are described in the literature, and it was expected that additional deposits could be found. In particular, it was hoped that a long series of varves could be found in deep water in the Great Lakes basins by core sampling.

By the end of the first season's field work (summer of 1950) it was apparent that very little new varved clay material could be found. Core samples from deep water in Lake Michigan contained a maximum of 150 annual layers, and newly discovered laminated clay deposits in Michigan and in Ontario east of Lake Superior were disappointing. Further, when the known varves were logged it was found that correlation between deposits by comparing thickness variations was generally impossible except over very short distances. A more fundamental difficulty became apparent as a result of study of the field observations and in a critical review of the literature; the events of late Pleistocene and Recent time were hot known as completely as is possible, and the generally accepted sequence of the events was in error in some important respects.

The objective was revised at the beginning of the second year, to place emphasis on the discovery of previously unknown events and on more complete description of the late Pleistocene to present sedimentary deposits of the Lake Michigan basin. By the end of the second year (June, 1952) significant information on parts of the geological history of the Great Lakes had been obtained by this project, and other investigators had published information on other parts of the history. A few radiocarbon dates for glacial and lake features were available. It was now quite clear that the generally accepted history of the Great Lakes was seriously in error in some respects.

The principal objective, in this final report, is to present a revision of the geologic history of the Great Lakes. This revised history is based on the facts and in part on the conclusions reported in earlier monographs and other publications on the subject, it takes into account the recent papers dealing with parts of the lake history, and it utilizes the new information gained in the field and in the laboratory by the project.

In addition to the treatment of the historical aspects of the subject, a report is given on fathogram indications of the nature of the lake bottom. It is planned to present information on the deep water sediments of Lake Michigan and their relation to the limnologic environment, in a supplement to the report.

History of the Project

This project on "Pleistocene chronology of the Great Lakes region" was established on July 1, 1950, by contract between the Geophysics Branch, Office of Naval Research, Department of the Navy, and the University of Illinois. The principal investigator and technical Head of the project was Professor Jack L. Hough of the Department of Geology, University of Illinois. The principal investigator devoted full time to the project only during his summer vacation periods and otherwise carried on his normal academic activities and duties as editor of a technical journal.

Other personnel of the project consisted of graduate and undergraduate students at the University of Illinois who engaged in the field work and some of whom carried out laboratory studies and used project information for their Master's theses.

Field work was carried out during the first summer session (1950) by four parties of two men each. Three parties, each headed by a graduate student, made investigations on shore in Wisconsin, Michigan, and Ontario, under the direction of the principal investigator.

The fourth party, consisting of the principal investigator and a graduate student, prepared core sampling equipment and engaged in bottom sampling operations in Lake Michigan. The United States Coast Guard, under a request initiated by the Office of Naval Research, assigned a vessel for the lake work.

Field work was carried out during the second summer season (1951) by a party of two consisting of the principal investigator and a graduate student. This work consisted of bottom sampling operations and sounding over a large part of Lake Michigan, and it was made possible through the courtesy of the United States Fish and Wildlife Service in providing the facilities of a research vessel.

Field work during the third summer (1952) was limited to a small amount of observation on shore by the principal investigator. The remainder of that summer was utilized by the principal investigator for study of data and for preparation of reports and copy for illustrations.

The project has been terminated on January 31, 1953. At this time it is possible to present a summary of results and conclusions which, in the opinion of the writer, constitute an adequate attainment of the objectives of the research within the scope of a project of this size. It is considered desirable to present for publication, in the standard geological journals, the details of several aspects of the work, and to prepare for publication a monographic treatment of the history of the Great Lakes. The writer has not requested an extension of the project, but he plans to complete writing of reports for publication without further aid from the project.

The subjects considered in the present report are by no means exhausted; the material presented here should serve as a foundation for much future research.

Acknowledgements

Bottom sampling work in Lake Michigan during the summer of 1950 was made possible by the United States Coast Guard, in providing the buoy tender _Woodbine_. The cooperation of the Commanding Officer of the _Woodbine_, F. A. Goettal, and his officers, and particularly the Chief Boatswain's Mate Bruno Konieczka, are acknowledged.

Bottom sampling and sounding operations in Lake Michigan during the summer of 1951 were made possible by the United States Fish and Wildlife Service through Dr. James W. Moffett, Chief, Great Lakes Fishery Investigations, in providing the facilities of the research vessel _Cisco_ during a two-weeks period. Captain Vernon Seaman and Chief Engineer Clifford LaLonde of the _Cisco_ rendered invaluable assistance beyond the call of duty.

University of Illinois students who directed parts of the field program and who carried out a part of the research on the materials collected are the following: Donald C. Baldwin, Raymond F. McAlister, and Maxwell Silverman. Other University of Illinois students who were not officially connected with the project but who have studied some of the materials collected and contributed data which are quoted in this report are Donald B. Snodgrass, Jane Gray, and Frank L. Staplin.

Analysis of lake sediment samples by X-ray diffraction and differential thermal analysis were provided by Prof. Ralph W. Grim of the Department of Geology, University of Illinois. Prof. Max Matteson of the Department of Zoology, University of Illinois, identified shells found in some of the core samples.

Outline of Work Performed

In preparation for this project a survey was made of the literature on the Pleistocene and Recent deposits of the Upper Great Lakes region, and all occurrences of laminated clay were noted.

The greatest part of the field work during the first summer, 1950, was carried out in northeastern Wisconsin, in Michigan between Grand Traverse Bay and Sault Ste. Marie, and in Ontario from Sault Ste. Marie 60 miles northward along the shore of Lake Superior to the Montreal River and northward about 80 miles along the Algoma Central and Hudson Bay Railway to Batchewana. Most of the known exposures of laminated clay in these areas were visited, and a search was made for additional laminated clays both in outcrop and by boring.

Thickness logs were made of a large percentage of the laminated clays which appeared to be varved, or laminated in annual layers. After these logs were re-plotted as thickness curves, an attempt was made to discover possible correlations between portions of the various deposits, in the hope that a continuous time-scale could be worked out which would extend through several separate deposits. Very few correlations were found, however, and this part of the work therefore yielded little information of value except to give figures for the minimum ages of several separate deposits.

In the course of the varved clay logging work, observations were made on features such as abandoned beaches and river terraces, glacial lake deltas, and other features related to late-glacial events. These observations were of considerable value in a later study of the history of the Great Lakes.

Another part of the field work during the 1950 summer season was the taking of eleven long core samples from deep water in Lake Michigan. The original purpose of this work was to find, if possible, a long sequence of laminations in the lake clay which might serve as a master record of the varve-thickness variations for the region. Only about 150 possible annual layers were found in the lake, however, and the hope of developing a time-scale based on varves was abandoned. Other features of the core samples appeared to record depositional events of importance, and a further study of the lake bottom deposits was therefore considered to be advisable.

Field work during the summer of 1951 was limited to sampling and sounding operations in Lake Michigan. A total of 126 bottom-sampling stations was made, 82 of which yielded core samples, and fathogram records were obtained along all of the courses run. The area covered in this work embraces more than a third of the lake, lying between a course from Sturgeon Bay, Wisconsin, to Point Betsie (near Frankfort), Michigan, and a course from South Haven, Michigan, to Milwaukee, Wisconsin.

All of the longer core samples were taken to the laboratory intact and then opened and studied. Most of the shorter core samples were extruded from the coring tube and logged immediately upon collection, and parts of these were saved for further detailed study.

Samples of the Lake bottom materials were analyzed for mechanical composition, carbonate content, identity of clay minerals, and other mineral and rock constituents, and various organic remains were studied. The details of this work are described in various later sections of the report dealing with results of the work.

RESULTS

GENERAL STATEMENTS

Training of Personnel in Submarine Geology

A by-product of the project has been the training of two men who have gone into the field of submarine geology. One, Mr. Maxwell Silverman, left the project and joined the staff of the Chesapeake Bay Institute of Johns Hopkins University, where he was in charge of the field program in submarine geology. A year later he joined the staff of the Oceanography Branch, U. S. Navy Electronics Laboratory, in San Diego. The other man, Mr. Raymond F. McAlister, went to the Scripps Institution of Oceanography for advanced work in submarine geology.

Most of the other students who worked on the project have since been employed in the petroleum industry.

Theses Resulting from Work of the Project

Three Master's theses resulting from the project were prepared by graduate students in the Department of Geology, University of Illinois, as partial fulfillment of the requirements for the degree of Master of Science. Two of the authors of these theses, Mr. Baldwin and Mr. McAlister, were employed by the project for work in the field, but they carried out laboratory and office work on their own time. The third author, Mr. Snodgrass, was not employed by the project, but he made studies of lake bottom samples collected by the project. In this way, some of the detailed work was accomplished at no cost to the project.

These three theses contain much detailed information which is not presented in this final report. Some of that information may be of use to specialists, and it may be obtained by consulting the theses which are on file in the University of Illinois Library. Following are the thesis titles:

Baldwin, Donald C. (1951) Late Pleistocene clays of the Sault Ste. Marie area and vicinity.

McAlister, Raymond F. (1951) Varved clays of the Goulais River Valley of Ontario.

Snodgrass, Donald B. (1952) A study of Lake Michigan bottom sediments.

There are four additional theses in the University of Illinois Library to which it is appropriate to call attention. These were written before the present project was established, but they bear on the subject of the project and they did, in fact, result from preliminary investigations which led to the initiation of the project. These theses are as follows:

Eveland, Harmon E. (1948) Topographic expression of geology in the Lake Huron basin.

Irvin, William C. (1948) The topographic expression of the sub-lacustrine geology of the Lake Superior basin.

Threet, Richard L. (1949) Geology and the origin of the Lake Ontario basin.

Weinberg, Edgar L. (1948) Deep water sediments of western Lake Huron.

Publications Resulting from Work of the Project

Because the work of the project has no military classification, it is contemplated that all of the principal results and conclusions will be published. The publication status as of the date of this report is as follows.

Published articles:

Hough, J. L. (1952) Fathogram indications of bottom materials in Lake Michigan: Journal of Sedimentary Petrology, vol. 22, pp. 162-172. (Reprints of this article are presented in the present final report.)

Silverman, M., and Whaley, R. C. (1952) Adaptation of the piston coring device to shallow water sampling: Journal of Sedimentary Petrology, vol. 22, pp. 11-16. (This paper is in part a result of the present project and in part a result of further developments at the Chesapeake Bay Institute, where the present writer was consultant to an Office Naval Research project.)

Articles in preparation for publication:

Hough, J. L., A low-water stage of Lake Michigan indicated by bottom sediments. (This material is included in the present report. It was given orally at the Geological Society of America meetings in Boston on November 14, 1952, and will be submitted to the Bulletin of the Geological Society of America for publication.)

Hough, J. L., Deep-water sediments of Lake Michigan. (This article is accepted for publication by the Journal of Sedimentary Petrology.)

Hough, J. L., Revision of the Nipissing stage of the Great Lakes. (Accepted for oral presentation at the Illinois State Academy of Science meetings, May 8-9, 1953. Manuscript to be submitted for publication in the Transactions of the Illinois State Academy of Science. The material is included in the present report.)

Introduction to Report of Results

The principal results of the research performed under this contract are presented under these headings:

Pleistocene climatic record in ocean bottom core samples.

The geologic history of the Great Lakes.

Fathogram indications of bottom materials in Lake Michigan.

Deep-water sediments of Lake Michigan.

The first two subjects are presented in detail in this mimeographed report. The third, "Fathogram indications of bottom materials in Lake Michigan", is given in abstract only but reprints of the published paper on this subject are appended as Supplement No. 1 (in pocket). The fourth subject, "Deep-water sediments of Lake Michigan", is given in abstract only. It is planned to distribute reprints of a published paper on this subject, when they are available, as Supplement No. 2.

PLEISTOCENE CLIMATIC RECORD IN OCEAN BOTTOM CORE SAMPLES

The basic information given here did not result from the work of the project, but a discussion of the available ocean bottom data is in order in a study of the Pleistocene chronology of the Great Lakes region. Core samples obtained in the North Atlantic Ocean by C. S. Piggot, and in the Ross Sea, Antarctica and in the southeastern Pacific Ocean by the writer, contain records of climatic fluctuations. The sediments of all of these cores have been dated by W. D. Urry, using the percent of equilibrium method for uranium, ionium and radium. All of the core samples mentioned contain records of events of the last 70,000 years, and some of them record events of earlier Pleistocene time. A summary of this information is presented here, and its application to the chronology of the Great Lakes region is suggested.

The longest detailed record available is contained in a southeastern Pacific Ocean core sample (Hough, in press, 1953), taken at Latitude 08°56.2' S. and Longitude 92°05.2' W., and from a depth of 12,900 feet. This core contains several layers of red clay separated by globigerina ooze. Because calcium carbonate is more soluble in cold water, the red clay layers (with low carbonate content) are interpreted as records of cold-water deposition and the globigerina ooze layers (with high carbonate content) are interpreted as records of warmer water deposition. These indications of water temperature at time of deposition may, further, be indications of colder and warmer climatic conditions. The writer's interpretation of this Pacific Ocean core is given in table 1, where it is compared with the standard Pleistocene chronology of North America. The

TABLE 1. - The Pleistocene chronology of North America compared with a dated climatic record of a southeastern Pacific Ocean core sample.

Southeastern Pacific [1]		Central North America [2]	
Time scale in years	Water temperature indications	Event	Estimated age
0-5000	cool		
6000	warm	Thermal maximum	5000 or 6000
7-12,000	cool		
	warm		
15,000	cold		
	warm		
26,000	cold	Wisconsin glacial stage	
	warm		
37,000	cold		
	warm		
51,000	cold		55,000
	warm		
64,000	cold		100,000
	warm	Sangamon interglacial stage	
274,000	cold	Illinoian glacial stage	
	warm		
310,000	cold		325,000
	warm		
330,000	cold		
	warm	Yarmouth interglacial stage	
700,000 ≁	cold	Kansan glacial stage	700,000
		Aftonian interglacial stage	
		Nebraskan glacial stage	1,000,000 ≁

1/ Data from Hough, J. L. (1953) Pleistocene climatic record in a Pacific Ocean core sample: Jour. Geology. (In press).

2/ Data from Flint, R. F. (1947) Glacial geology and the Pleistocene epoch, New York, John Wiley & Sons, table 30, p. 532.

estimated dates for North America are based mainly on calculations of the time required to develop weathering profiles on the various glacial deposits. The dating method used for the Pacific Ocean core is considered valid to an age of 300,000 years (Urry, 1942), and the time scale was extrapolated to obtain dates beyond this age. Three cold periods occur in the range considered referable to the Illinoian glacial stage, and these may be considered Illinoian glacial substages. It is interesting to note that there are three principal Illinoian moraines in North America (Leighton and Willman, 1950, p. 602).

Because there is good correlation between the dated cold periods of the Pacific record and the generally accepted events of the Pleistocene of North America, from the Kansan glacial age to the present, it appears reasonable to accept the time scale of the Pacific record as the most accurate scale available.

Table 2 gives the detailed records of the last 70,000 years in core samples from the Antarctic, North Atlantic, and southeastern Pacific, and includes a tentative correlation with the chronology of the Great Lakes region. The first three columns of table 2 present the dated climatic indications for the three widely separated oceanic areas. The sources of this information are Hough (1950) for the Antarctic column, Bramlette and Bradley (1940) and Piggot and Urry (1942) for the North Atlantic column, and Hough (1953) for the southeastern Pacific column. The fourth column presents a summary of the first three, in which relatively minor differences in date and in intensity of climate are reconciled. This shows six distinctly cold climatic periods centered at the following dates: 11,000, 15,000, 26,000, 40,000, 51,000, and 61,000 years ago. Column five of Table 2 presents a suggested <u>tentative</u> correlation of these dated oceanic cold periods with events in the Great Lakes region.

TABLE 2. – The Wisconsin glacial stage chronology of the Great Lakes region compared with dated climatic records of core samples from the Antarctic, the North Atlantic, and the southeastern Pacific Oceans.

Time scale (years)	Ross Sea, Antarctica	North Atlantic	Southeastern Pacific	Summary, columns 1,2,&3.	Suggested tentative correlation with events of Great Lakes region
		normal	cool		
				cool	
	cold		cold		
		cold	cool		
5,000					
	warm	warm	warm	warm	Thermal maximum
		normal		cool	
10,000			cool		
	cold	cold		cold	MANKATO SUBSTAGE
	warm	normal	warm	warm	
15,000					
			cold	cold	Port Huron
		cold			
20,000					
			warm	cool	CARY SUBSTAGE
	cold				
		warm		warm	
25,000					
			cold		Valparaiso
				cold	
		cold			
30,000					
			warm		
	warm	cool		warm	
35,000					
			cold		
40,000			cool	cold	Bloomington
		cold			
45,000					
			warm	warm	
		warm			
50,000					
	cold	cold	cold	cold	Shelbyville
55,000		normal	cool		
				warm	
			warm		
60,000		cold			
				cold	FARMDALE SUBSTAGE
			cold		
65,000					
		warm	warm	warm	
70,000					

The only event in column five (table 2) which is dated with any degree of accuracy is the Mankato glacial substage. This was dated by applying the radiocarbon method to wood found incorporated in the lower part of the Mankato drift at Two Creeks, Wisconsin (Arnold and Libby, 1951). Flint and Deevey (1951, p. 263), after considering the geologic relations of the dated wood samples, give "a round figure of 11,000 years for the Mankato maximum." This age applies to the Mankato drift in the Lake Michigan lobe. Thwaites (1937), before radiocarbon dates had been obtained, subdivided the Mankato into Early (red drift of the Michigan and Superior basins) and Later (Des Moines lobe west of the Mississippi River). Radiocarbon dates for wood incorporated in the lower part of the Mankato till near Ames, Iowa, average about 12,000 years in age (Libby, 1952) and thus indicate that the two events of Thwaites' subdivision were approximately contemporaneous and therefore Thwaites' "Early" and "Later" classification must be discarded. The Mankato substage very likely is susceptible to subdivision on the basis of other evidence. Within the Michigan-Superior area there are many successive Mankato moraines, and detailed study of their relationships may provide new subdivisions. Late glacial events in the Lake Ontario basin and in the entire region north of the Great Lakes in Canada are little known.

The writer believes that the 15,000 year old cold period of table 2 is represented by the Port Huron morainic system, for the following reasons. Bretz (1951b, pp. 412-414) has shown that the previously accepted correlation of Port Huron drift on the eastern shore of Lake Michigan with the red Mankato drift on the western shore is incorrect. He found that red Mankato drift occurs in a relatively narrow belt along the eastern shore of Lake Michigan, cutting across the truncated ends of the Port Huron moraines between Ludington and Whitehall, and extends southward to Muskegan, Michigan, beyond the limits of the Port Huron drift. The writer found, in the course of bottom sampling operations of the project, that red till occurs on the bottom of Lake Michigan at two points southwest of Muskegon, well out in the southern basin of the lake. The red Mankato drift was obviously deposited by a distinctly later ice advance than the one which built the Port Huron system.

A major retreat of the ice is required between the Port Huron and the Mankato ice advances, in order to account for the red color of the Mankato drift. None of the older glacial drift deposits in the region possesses the red color of the Mankato. Some of the tills, notably the Bloomington, have a reddish or pinkish mottling, but they generally are not uniformly red. The strongly red Mankato till overlies red lake clay, and it is generally believed that the till is red because the ice which deposited it over-rode extensive deposits of red clay and incorporated that material in the till. The full significance of this explanation has not previously been appreciated. The red till occurs at or near the lake shores, from the northwestern side of Lake Superior, around the western end of that lake, eastward to the Green Bay area; it occurs on both sides of Lake Michigan (as well as on the bottom of Lake Michigan), and extends into the Lake Huron basin. Because of this, the basins of Lakes Superior, Michigan, and Huron must have been largely (if not entirely) free of ice to permit the widespread deposition of the red clay which was later incorporated into the Mankato drift in sufficient amount to give it a strong red color throughout the region described.

Further evidence of a major retreat in post-Port Huron, pre-Mankato time is the well known Two Creeks forest bed, which required a lowering of Lake Michigan below the level of the Chicago outlet. For this lowering to be possible, the waters of Lake Michigan must have drained northeastward from the Michigan basin (because no low outlet exists elsewhere) to a low-level Lake Huron, and from there eastward across ice-free areas to the St. Lawrence valley. No other, sufficiently low, course of drainage is available south of this course.

From the preceding discussion it is concluded that the Port Huron-Mankato interval is an interglacial substage. This appears to correlate with the warm interval centered at 13,000 years, as shown in table 2. Further, the Port Huron glacial event, represented by a massive and extensive morainic system, appears to correlate with the immediately preceding cold climatic period which is centered at 15,000 years.

The Cary glacial substage generally is considered to include the Valparaiso morainic system, the Tinley moraine, and the Lake Border morainic system in Illinois, western Indiana, and Michigan. Bretz and the writer include the Port Huron morainic system as the latest part of the Cary. The series of moraines from the Valparaiso to the Port Huron apparently records a series of glacial advances and retreats through a relatively long period of time, with no major interstadial breaks. Because of this, the writer suggests that the Valparaiso morainic system correlates with the cold period centered at 26,000 years (in table 2), and that the Tinley and Lake Border advances and the intervening retreats occurred during the time between the 26,000 and 15,000 year cold periods. In the Antarctic and North Atlantic columns of table 2 this entire interval of time is represented by cold climate sediments, except for the presence of a warm-water fauna at 24,000 years in the North Atlantic.

In the Erie basin the Wabash-Fort Wayne series of moraines generally is considered to be early Cary in age, and the Defiance and Erie Lake Border moraines are included in the Cary. The writer suggests that the Wabash-Fort Wayne series is correlative with the Valparaiso system of Illinois and western Indiana, that the Defiance is correlative with the Tinley, and the Lake Border systems of the two basins are correlative. There is evidence suggesting that a glacial retreat of considerable magnitude occurred in the Erie basin between the times of deposition of the Fort Wayne moraine and the Defiance moraine. Shepps (1953) has shown that the Defiance age till in eastern Ohio has a much higher content of silt and clay than does the earlier till. White (G. W. White, personal communication) has suggested that this indicates that the ice retreated from a large part of the Erie basin, allowing the deposition of fine-grained lake sediments, and that the advancing Defiance ice incorporated these fine-grained sediments into the Defiance till.

The Fort Wayne-Defiance interval retreat, here considered correlative with the Valparaiso-Tinley retreat, is correlated with the brief warm period shown at 24,000 years in table 2.

If the foregoing correlations are correct, there remain three cold periods of the oceanic record, at 61,000, 51,000, and 40,000 years, to be correlated with glacial substages of the Great Lakes region. The generally accepted classification of the Wisconsin stage in central North America embraces the following four substages: Mankato, Cary, Tazewell, and Iowan (Ruhe, 1952). Leighton and Willman (1950) have proposed a fifth, earlier, substage and named it the Farmdale. No till representing the Farmdale has been found, but the glacial substage is inferred from "a silt deposit which lies on the weathered zone and erosional slopes of the Illinoian drift and which has a very youthful profile of weathering beneath the Peorian loess" (Leighton and Willman, 1950, p. 602). The relationships of this Farmdale silt to topography and to the Illinois River valley indicate that it is a loess and strongly suggest a valley-train source. This, in turn, implies an extension of an ice sheet during a Farmdale substage prior to the Iowan substage. Till deposits of the Farmdale, if they exist, have not yet been found because subsequent ice advances overrode the area covered by the Farmdale ice. In table 2 the earliest Wisconsin cold period, centered at 61,000 years in column four, is correlated with the Farmdale glacial substage.

The generally accepted Iowan and Tazewell substages remain as possible correlatives of the cold periods at 51,000 and at 40,000 years.

If all of the foregoing suggested correlations are correct, correlatives have been found in the Great Lakes region for all of the cold periods of the oceanic record. In Illinois, however, the Shelbyville and Bloomington morainic systems (generally accepted as parts of the Tazewell substage) appear to be sufficiently distinct to be considered as separate substages. Their areal relationships suggest this, and soil development on the Shelbyville till under the Bloomington till also suggests this (G. E. Ekblaw, personal communication). It appears possible, therefore, that the Shelbyville and Bloomington systems are correlative with two separate oceanic cold periods. In the writer's understanding of the present status of knowledge of the Iowan-Tazewell relationships, it appears reasonable to consider the possibility that the Iowan and the Shelbyville can be correlated with a single oceanic cold period centered at 51,000 years, and that the Bloomington can be correlated with the cold period centered at 40,000 years.

The correlations suggested in the foregoing paragraphs, with the exception of the Mankato substage correlation, are considered by the writer as tentative. They are made as working hypotheses only.

THE GEOLOGIC HISTORY OF THE GREAT LAKES

Introduction

The Great Lakes stages and their relationships to glacial events were studied in detail by several early geologists and a large number of papers on the subject were published in the period between 1890 and 1910. The conclusions of this great amount of early work were presented in detail by Leverett and Taylor in the United States Geological Survey Monograph 53, which was published in 1915. For the next twenty-one years there were essentially no new contributions to the subject, then Stanley (1936, 1937, and 1938) published the first serious revision of a part of the history. The next important contributions were made by Bretz, in 1951, and the work of the present project has added further information. Radiocarbon dates have been obtained for some of the events of the lake history. It is now possible and timely to prepare a revision of the entire history of the Great Lakes stages. Results obtained by the project which bear on the subject will be presented at appropriate places in the history.

The geologic history of the Great Lakes, as given in this report, will be detailed where serious revision is made of the generally accepted story and will be brief in those parts where the older published accounts are essentially unmodified. In general, this history is based on the monograph of Leverett and Taylor (1915) except where otherwise noted.

The Great Lakes basins almost certainly acquired their major topographic forms in pre-Pleistocene time, by normal subaerial erosion and stream development acting on a region with a variety of bed rock formations of differing resistance to erosion. All of the lake basins with the exception of Superior are intimately related to shale formations or other "weak" rock belts while the lake shores and the higher parts of the region are in many places determined by more resistant rock. It is reasonable to assume that the ice of the early Pleistocene glacial stages was guided to a considerable extent by major topographic features which still exist today. It further appears that by Cary substage time the shapes of the glacial lobes conformed closely to the Great Lakes basin configurations.

Because Valparaiso ice of the Cary substage completely filled the Great Lakes basins and extended beyond them to the south, it is likely that the records of pre-Cary lakes, if such existed, have been largely destroyed. For this reason, the history of lake stages in the Great Lakes basins begins in post-Valparaiso time. Marginal lakes were impounded in some places between the edge of the Valparaiso ice and higher divides to the south, but this history is not concerned with them.

The evidence for the existence of lake stages at various levels in the Great Lakes basins consists mainly of the following; (1) gravel and sand deposits having the appearance of present-day beach deposits, topographically as well as in their texture and structure; (2) notches in the land profiles, apparently wave-cut, consisting of steep banks and gently sloping benches, many of which are associated with beach-type deposits; (3) abandoned channels which apparently served as outlets of the lakes; and (4) abandoned delta deposits in the valleys of streams tributary to the lakes.

Detailed descriptions of the various abandoned beaches are given or are referred to in the monograph by Leverett and Taylor (1915), and it is not necessary to present this information here. The existence of lake stages at the various levels reported is, in general, unquestioned. The sequence of occurrence of various stages within a single lake basin is a matter of interpretation, and the correlation of the sequence worked out for one basin with the sequence in another basin is a matter of further interpretation. Some of the interpretations given by Leverett and Taylor must be rejected because of new evidence, and other interpretations are open to serious question because of a lack of evidence. In presenting the present revision, an attempt will be made to indicate the distinction between the more certainly established basic information, the more probably correct first-order interpretations, and more questionable second-order interpretations.

The First Glacial Great Lakes

By way of introduction to the lake history, the following interpretations are presented: In late Valparaiso time the ice front retreated into the Michigan and Erie basins, and water impounded between the ice and the moraines beyond it became the first glacial Great Lakes of which there is a clear record. The time at which this occurred can not be stated with assurance, but it is estimated, on the basis of the tentative chronology presented in table 2 (page 15), that these first lakes came into existence about 24,000 years ago. Lakes appeared in the Huron basin somewhat later, and they appeared in the Ontario and Superior basins still later. The lakes changed in level and in extent as a result of fluctuation in position of the glacial ice border, as a result of downcutting of outlet channels, and as a result of warping of the land. Many of the events occurring in the different lake basins were closely related, but it is considered desirable to present the history of each lake basin separately, for the earlier stages, before discussing the correlations between basins.

Lake Stages in the Michigan Basin

A summary of the lake stages which have existed in the Lake Michigan basin, as inferred from the evidence of abandoned beaches and other evidence which will be cited later, is given in tables 3 and 4. All of these stages have been named, but the names of some have been omitted from the tables because their identification is questionable.

TABLE 3. - Lake stages of the southern half of the Lake Michigan basin, listed in order of elevation.

Elevation in feet A.T.	Name
640	Glenwood
620	Calumet
605	Toleston
591	--------
581	Present Lake Michigan
below 581	Two Creeks low stage
230	Chippewa

All of the beaches of stages listed in table 3 are horizontal in the southern half of the Lake Michigan basin, indicating that no warping of the land has occurred in that area since the beaches were formed.

TABLE 4. - Beaches of the northern part of the Lake Michigan basin, in the warped area.

Relative position	Name
highest	Algonquin
	Battlefield
	Nipissing
	Algoma
lowest	Present Lake Michigan

The beaches above present lake level which are listed in table 4 are warped, and rise to the northward. None of the beaches above the present lake in the warped northern area can be traced southward to a connection with any beach in the southern half of the lake, because shore erosion by the present lake has cut away the upper beaches in the critical areas just north of the "hinge line" or just north of the unwarped area. It is certain, however, that the two highest beaches of the south end of the lake, the Glenwood and Calumet, have no correlatives in the north because they terminate at or on the southern margin of the Mankato drift in the latitude of Milwaukee and Grand Haven. The Algonquin beach of the northern area descends from an elevation of 809 feet at Mackinac Island to an elevation of 619 feet at Traverse City. It is probable that this beach formerly extended southward and joined with the Toleston level beach at an elevation of 605 feet. The Nipissing beach of the northern area descends less rapidly, and it is possible that it also formerly extended southward and joined with the Toleston level beach at an elevation of 605 feet. These possibilities will be discussed later. The various lake stages did not necessarily occur in the order of their elevations. Consideration of the elevations and extent of the beaches in relation to glacial moraines and other features has led to various interpretations of the sequence of events. The interpretation accepted by the present writer is given in figure 1, and the evidence for this interpretation is presented in the following text.

<u>Early Lake Chicago</u>. - When the ice front retreated from the Valparaiso moraine at the south end of the Lake Michigan basin, an early Lake Chicago must have been formed by water impounded between the ice

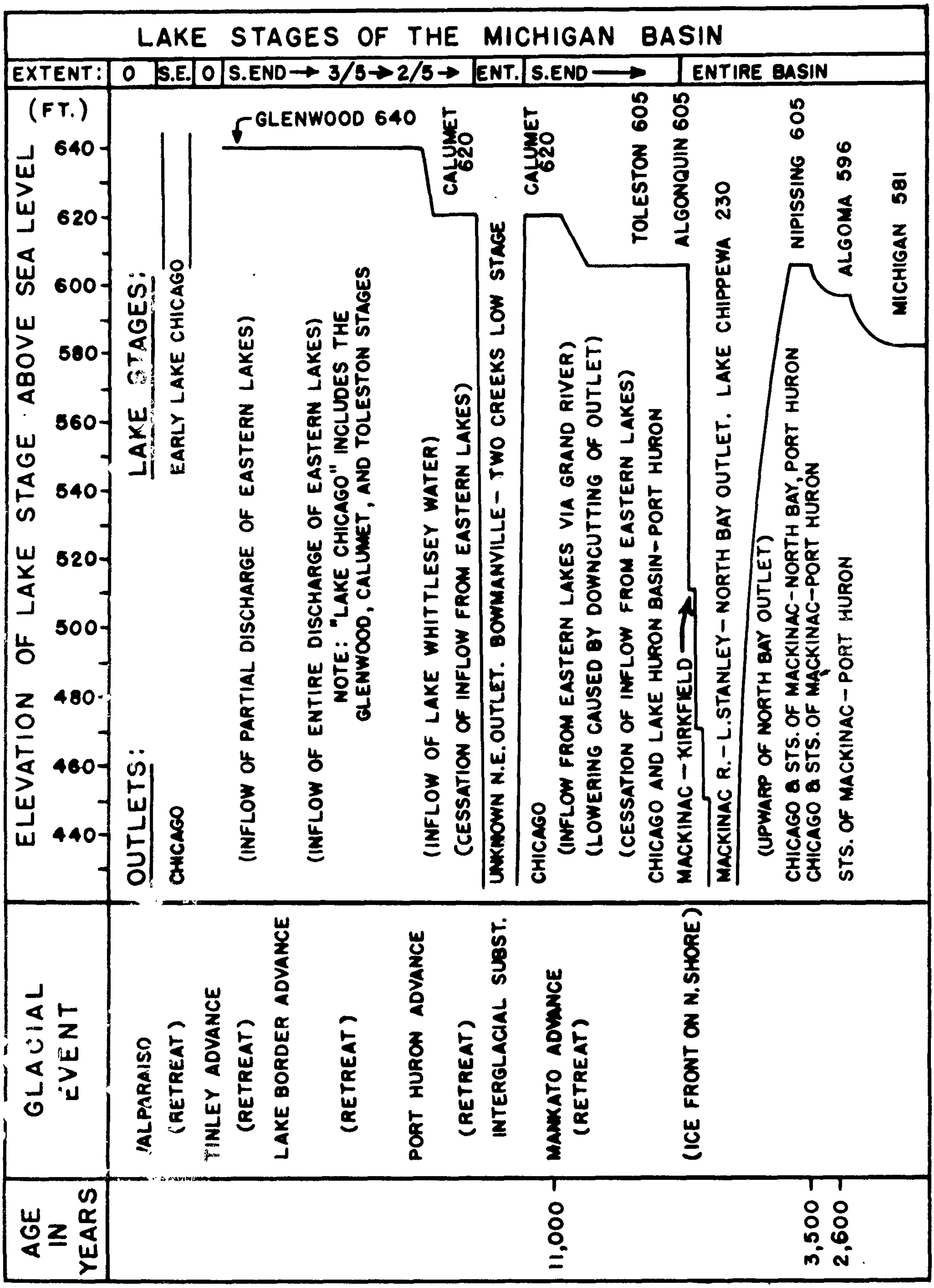

FIG. 1. - Lake stages of the Michigan basin.

and the moraine. (See fig. 11; all of the lake stage maps are grouped together at the end of the lake history section of this report.) According to Bretz (1951b), meltwater and probably glacial lake water discharged through two trans-morainic valleys west of Chicago and flowed down the Desplaines valley to the Illinois River. During this time free drainage was established through the Valparaiso moraine at about the level of the future Toleston stage.

<u>The Tinley glacial advance</u>. - When the ice advanced to the Tinley moraine it again filled the Lake Michigan basin and thus destroyed Early Lake Chicago (fig. 12). The Tinley moraine was deposited along the inner slope of the Valparaiso moraine in the Chicago region, and it filled the pre-existing gaps in the Valparaiso moraine. Tinley outwash built a valley train in the outlet river which was graded up to an elevation of about 630 feet at the moraine (Bretz, 1951b).

<u>The Glenwood stage of Lake Chicago</u>. - The earliest beach in the Lake Michigan basin is the Glenwood, with an average elevation of 640 feet A.T. The Glenwood stage of the lake came into existence after the ice front retreated from the Tinley moraine (fig. 13). It is probable that the first ponded water stood slightly higher than the Glenwood beach, because the Tinley moraine crests in the two trans-Valparaiso valleys probably were slightly higher than the adjacent valley train surfaces in the outlet channels. If this were true, it is likely that the spillways over the moraine were rapidly cut down to the valley train level. Bretz (1951b) describes a boulder pavement on remnants of the channel floor of the outlet, probably developed by concentration of the coarser constituents of the till which was eroded in the first, rapid lowering of the lake to

the Glenwood level.

The Glenwood stage endured for a long time; certainly through the times of the next glacial retreat and advance, and perhaps longer. The reason for this static period and stability of the outlet channel apparently is that the outlet channel was graded to a stable profile by the previously deposited Tinley valley train, and the boulder concentration described by Bretz served as a protective pavement of the channel floor.

The Lake Border glacial advance. - The next glacial advance nearly filled the Lake Michigan basin, but it stopped short of the southern divide in Indiana and in Illinois. Lake Chicago, still at the Glenwood stage, was constricted to a crescent-shaped body of water on the Chicago plain between the ice front and the Tinley moraine (fig. 14). It continued to discharge through the "Chicago outlet," the two trans-moraine channels which join downstream in the Desplaines valley. The Lake Border morainic system was deposited.

Retreat of the Lake Border ice. - After the deposition of the Lake Border morainic system the ice front retreated at least half-way up the Lake Michigan basin, because the subsequently deposited Port Huron moraine lies that far north. The Glenwood stage of Lake Chicago persisted at least until the retreating Lake Border ice front had reached the vicinity of Muskegon, Michigan (105 miles north of the south end of the lake), because the Glenwood beach extends that far north (fig. 15). It is impossible to determine whether the Glenwood stage persisted after the Lake Border ice retreated north of Muskegon because Mankato glacial drift overlaps the Port Huron moraine and extends southward to Muskegon, and the Glenwood beach is not present on the Mankato drift (Bretz, 1951b).

The Port Huron glacial advance. - The next glacial advance, the Port Huron, is represented by a strong moraine which has been traced from its type locality at Port Huron, Michigan (at the south end of the Huron basin) to the Lake Michigan basin where it passes south of Grand Traverse Bay and extends southwestward past Ludington, Michigan, and nearly to Whitehall, Michigan. According to Bretz (1951b), this moraine is truncated and overlapped by the younger Mankato drift in the Ludington-Whitehall area. The Port Huron ice front probably reached the shore of the lake in the vicinity of Whitehall, extended across the Lake Michigan basin on a curving line (convex to the south), and reached the Wisconsin shore between Port Washington and Sheboygan. A Port Huron correlative on the Wisconsin shore of Lake Michigan has not yet been identified, but Bretz predicts that Port Huron moraines will be found among the gray till ridges which are mantled with younger red Mankato drift. The Port Huron moraine is the oldest glacial feature which actually has been traced from the eastern lake basins to the Michigan basin, and it therefore provides the first definite correlation of events in the eastern and western lakes.

Lake Chicago continued in existence in the Lake Michigan basin, and continued to discharge through the Chicago outlet (fig. 16). Whether the lake still stood at the Glenwood level or had been lowered to the next beach at the Calumet level is not known. The present writer believes it is probable that the Glenwood stage persisted during the Port Huron advance, for reasons which are given in the following section.

The Calumet stage of Lake Chicago. - The Calumet stage is recorded by a strong beach having an average elevation of 640 feet A.T. The present elevation of the floor of the Chicago outlet channel (approximately 590 feet A.T.) is well below the Calumet level and below the level of the next lower lake stage, the Toleston. Because of this it is certain that Lake Chicago could discharge its water through the Chicago outlet at both the Calumet and the Toleston stages. The present outlet channel floor is on bedrock a short distance down-stream from the transmorainic gap, and this bedrock floor accounts for the cessation of downcutting during the Toleston stage. The occurrence of glacial striae on the bedrock floor indicates that no erosion of the bedrock has taken place since retreat of the glacial ice from the channel area, and it thus indicates that the bottoms of the outlet channels of the earlier lake stages must have been stabilized on unconsolidated materials. The stabilization of the channel bottom during the Glenwood stage has been described.

Lake Chicago apparently was lowered from the Glenwood level to the Calumet level rapidly, because no distinct beaches occur between the shore deposits of those two stages. The lowering of the lake surface undoubtedly was due to downcutting of the outlet. The prolonged pause of the lake level at the Calumet stage must have resulted from a cessation of downcutting, while the channel was still in unconsolidated material. The most reasonable explanation of the Glenwood and Calumet static periods and of the periods of outlet deepening which followed each of them has been given by Bretz (1951b). This explanation is that during the Glenwood and Calumet periods of static lake level the outlet channel was stabilized in relation to a certain maximum discharge, and that each of the two periods of downcutting resulted from a greatly increased discharge. Because the lake remained at the Glenwood stage throughout the Tinley retreat, the

Lake Border advance, and at least a large part of the Lake Border retreat, it is apparent that fluctuations in the discharge of the Michigan basin alone cannot account for the downcutting of the outlet. The required additional discharge was contributed by overflow down the Grand River from lakes existing in the Huron and Erie basins to the east.

Bretz, in his explanation of the lowering of Lake Chicago from the Glenwood to the Calumet level, employed the discharge from a series of lakes in the eastern basins, the second and third Maumee stages, three Arkona stages, and the Whittlesey stage. These lake stages existed, in sequence, from the time of retreat of the Defiance ice in the Erie basin (correlated with the Tinley retreat in the Michigan basin, by the present writer), through the Erie Lake Border advance and retreat, and through the first Port Huron advance into the Huron basin. Bretz (1951b, p. 409) has stated: "Perhaps the most questionable element in this correlation of the Lake Chicago stages with the lake succession in the Huron and Erie basins is the assignment of most of Maumee's history and all of Arkona's and Whittlesey's to the first downcutting interval, during which Lake Chicago left no recognizable shore lines." The persistence of the Glenwood stage during a large part of the period of retreat of the Lake Border ice is proved by the extent of the Glenwood beach; if the Erie Lake Border ice can be correlated with the Chicago Lake Border ice, the Glenwood stage persisted during the time of Maumee discharge. The present writer believes that the entire episode of lowering of Lake Chicago from the Glenwood to the Calumet level probably occurred during the retreat of the Port Huron ice, when Lake Whittlesey was drained (fig. 17).

Lake Whittlesey was a large body of water covering an area more than twice the size of the present Lake Erie, and when it was drained its surface fell approximately 50 feet. The upper 40 feet of this body of water were above the sill at the entrance to the Grand River valley, but were held up by the Ubly channel and an ice dam. If the ice dam were removed rapidly, the upper 40 feet of the Whittlesey water would have been discharged rapidly. The discharge through the Chicago outlet during drainage of Lake Whittlesey was almost certainly greater than at any previous time. The lowering of Lake Chicago to the Calumet level must have been completed during the Port Huron retreat, even if it had begun earlier.

Lake Whittlesey was drained during the retreat of ice from the first, or main, Port Huron moraine in the Saginaw-Huron area, and Early- and Intermediate Lake Warren were the next two lower lake stages occurring there. These stages can be correlated with two later Port Huron advances, to the Bay City and Tawas moraines, respectively (Bretz, 1951a). This correlation will be discussed in greater detail in a later section.

If the Calumet stage of Lake Chicago was attained during the retreat of the first Port Huron ice, it persisted during the later Port Huron advances and retreats (while the Early- and Intermediate Lake Warren discharge was delivered to the Lake Michigan basin) until a new outlet was opened and the lake was lowered below the level of the Chicago outlet.

<u>The Two Creeks interglacial substage</u>. - After the Port Huron morainic system was deposited, and the Calumet stage of Lake Chicago had been established, the ice retreated far enough in the Michigan basin to allow the lake water to drain down at least as low as the present lake surface, abandoning the Chicago outlet (fig. 18). This is indicated by forest remains at Two Creeks, Wisconsin (15 miles north of Manitowoc) in which

logs, peat, and tree stumps in growth position occur down as low as the present lake surface, about 580 feet A.T. The lake must have been drained at least to that level. An outlet from the Lake Michigan basin low enough to permit this drainage can have existed only north of the Port Huron morainic system, somewhere along the northeastern edge of the basin. The most likely location of this outlet is believed to be the lowland extending from Little Traverse Bay eastward to the Huron basin. This lowland is floored by unconsolidated material, including Mankato drift which is younger than the low-water stage. The area in which the lowland lies has been warped upward since late Mankato time. If the area were depressed as much in late Port Huron time as it was in late Mankato time, it would have provided an outlet with a floor at least 100 feet below present lake level.

In order for the water in the Michigan basin to have drained down to 580 feet A.T. (it probably went lower), the water in the Huron basin to the east must have been at least that low, and a drainage course must have been open to the sea. Because there is no outlet as low as 580 feet A.T. anywhere along the western and southern borders of the Great Lakes region, the discharge must have gone down the St. Lawrence river valley. This implies a major retreat of the ice in the east.

There are strong indications that the Lake Superior basin also was abandoned by the ice at this time. These were discussed in the section of the report dealing with the Pleistocene climatic record in ocean bottom core samples, and will be referred to again in a section dealing with the Superior basin.

The Two Creeks interglacial substage was brought to a close by the advance of the Mankato ice.

<u>The Mankato glacial advance and the second Calumet stage</u>. - When advancing Mankato ice closed the low northeastern outlet of the Lake Michigan basin, the water in the basin rose until it spilled through the old Chicago outlet. This outlet had been abandoned at the Calumet level, and the new lake undoubtedly rose to the same level. There was, therefore, a second Calumet stage of Lake Chicago, in Mankato time (fig. 19).

The forest bed at Two Creeks, Wisconsin, was flooded by the water rising to the second Calumet stage, and several inches of silty sediment was deposited there. Then the advancing ice rode over the area, pushing over the trees which were standing (Wilson, 1932). Several samples of wood from these trees have been dated by the radiocarbon method, and the average age obtained is 11,400 ± 350 years (Arnold and Libby, 1951). Allowing 400 years for further advance to the position of maximum extent, Flint and Deevey (1951) accept a round figure of 11,000 years for the Mankato maximum.

The Mankato till at Two Creeks is strongly red in color, and has a high silt and clay content. This distinctive type of till is found around the western end of Lake Superior, in the Green Bay region, down the western side of the Lake Michigan basin to Milwaukee, and on the bottom of the lake. It occurs on the eastern side of the Lake Michigan basin from Muskegon (Bretz, 1951b) northward through Manistee and Benzie into Leelanau County (Leverett and Taylor, 1951, p. 308). The extent of the red till beyond Leelanau County is unknown to the present writer, except that he has observed it in one locality near the lake shore in the vicinity of Charlevoix.

Leverett and Taylor (1951, p. 308) describe the Manistee (red till) moraine as follows: "It wraps around the western end of prominent transverse ridges which come out as headlands along this part of the shore.... Between these transverse ridges the ice pushed into the lowlands for several miles from the shore of Lake Michigan, so that the moraine makes a series of loops in crossing the lowlands between the prominent ridges. Its appearance is as if the ice had made a readvance and had adjusted its border to these topographic features....The parts of the lowlands outside the Manistee moraine are covered with sand, apparently deposited from outwash....Some of these sand plains are 20 to 30 feet or more below the level of the outwash aprons that border the eastern ends of the prominent transverse ridges, apparently indicating that the outwash aprons were eroded before the Manistee moraine was developed." These relationships of the Manistee moraine indicate to the present writer that the Port Huron drift of this area was extensively eroded, probably during a low water stage of the lake, before the Manistee moraine was deposited. The period of erosion would be the Two Creeks interval.

In the opinion of the writer, the old correlation of the non-red Port Huron drift of Michigan with the red Mankato drift of Wisconsin and Michigan should be abandoned. Bretz rejected this old correlation (1951b, p. 424) and stated that the Port Huron morainic system is latest Cary in age. Bergquist (1952), however, still considers the Port Huron as of Mankato age.

The Calumet stage of Lake Chicago apparently persisted (in the southern third of the basin) until just after the time of maximum development of the Mankato ice (fig. 20), because a faint Calumet level beach occurs on the southern margin of the red drift on the west side of the lake (Bretz, 1951b). Meanwhile, in the eastern lake basins, advancing Mankato ice had dammed the low outlets which were in use during the interglacial substage and had raised the water levels there. Late Lake Warren of the Erie and Huron basins discharged down the Grand River valley and into Lake Chicago. It appears that this discharge, or more likely the still greater discharge of Late Lake Warren when the Mankato ice began receding, added to the discharge of the Lake Michigan basin, caused the downcutting of the Chicago outlet and the lowering of Lake Chicago from the Calumet level to the Toleston level.(fig. 21).

<u>The Toleston stage of Lake Chicago</u>. - The Toleston stage (fig. 22) is represented by shore features in the southern half of the Lake Michigan basin occurring at an average elevation of 605 feet A.T. Lake Toleston undoubtedly discharged through the Chicago outlet which, by Toleston time, was cut down to its present elevation. No further downcutting of the Chicago outlet since Toleston time has been possible because the outlet channel is on bedrock. The Toleston stage is considered as terminating when the retreating Mankato ice opened the Lake Michigan basin waters to communication with the Huron basin waters through the Little Traverse Bay lowland or the straits of Mackinac area. All evidence bearing on this part of the history in the Huron basin indicates that the water level there stood at about the same elevation as Lake Toleston, so that no appreciable change in level occurred when the two basins were joined.

The persistence of the Toleston level lake as Lake Algonquin was recognized by Leverett and Taylor (1915, p. 357). The present writer believes it probable that a still later lake stage, the Nipissing, rose to the Toleston level after a period of low water.

<u>Post-Toleston lake stages in the Lake Michigan basin</u>. - The Algonquin and subsequent lake stages of the Lake Michigan basin will be described in

a later section of the report, after the pre-Algonquin events in other lake basins have been reviewed.

Lake Stages in the Erie and Huron Basins

Highest Lake Maumee in the Erie basin. - The first lake of which there is definite record in the Erie basin was the Highest Lake Maumee, standing at an elevation of about 800 feet above sea level at the southwest end of the Erie basin at Fort Wayne, Indiana. This stage and the succeeding stages in the Erie basin are shown graphically in figure 2. Highest Lake Maumee discharged southwestward through the Fort Wayne moraine, and down the Wabash River to the Ohio and Mississippi Rivers (fig. 11). As in the Michigan basin, the first ponded water in the Erie basin may have risen to a higher level and then lowered rapidly to the level marked by an extensive high beach, as the outlet channel was developing a stable gradient.

The highest Maumee stage, at 800 feet, existed during the ice retreat from the Fort Wayne moraine, when the lake was expanding, and during the subsequent ice advance which built the Defiance moraine, when the lake was reduced in area (fig. 12). The extent of the retreat during the Fort Wayne-Defiance interval apparently was considerable. Taylor (in Leverett and Taylor, 1915, p. 322) suggested that the ice front, in retreating from the Fort Wayne moraine, did not stop at the position of the Defiance moraine but receded to a line at least 25 or 30 miles east of that position before readvancing to build the Defiance moraine. Recent work by Shepps (1953) has shown that the Defiance age till in eastern Ohio has a much higher content of silt and clay than the earlier till. This is interpreted as an indication that the ice retreated from a large part of

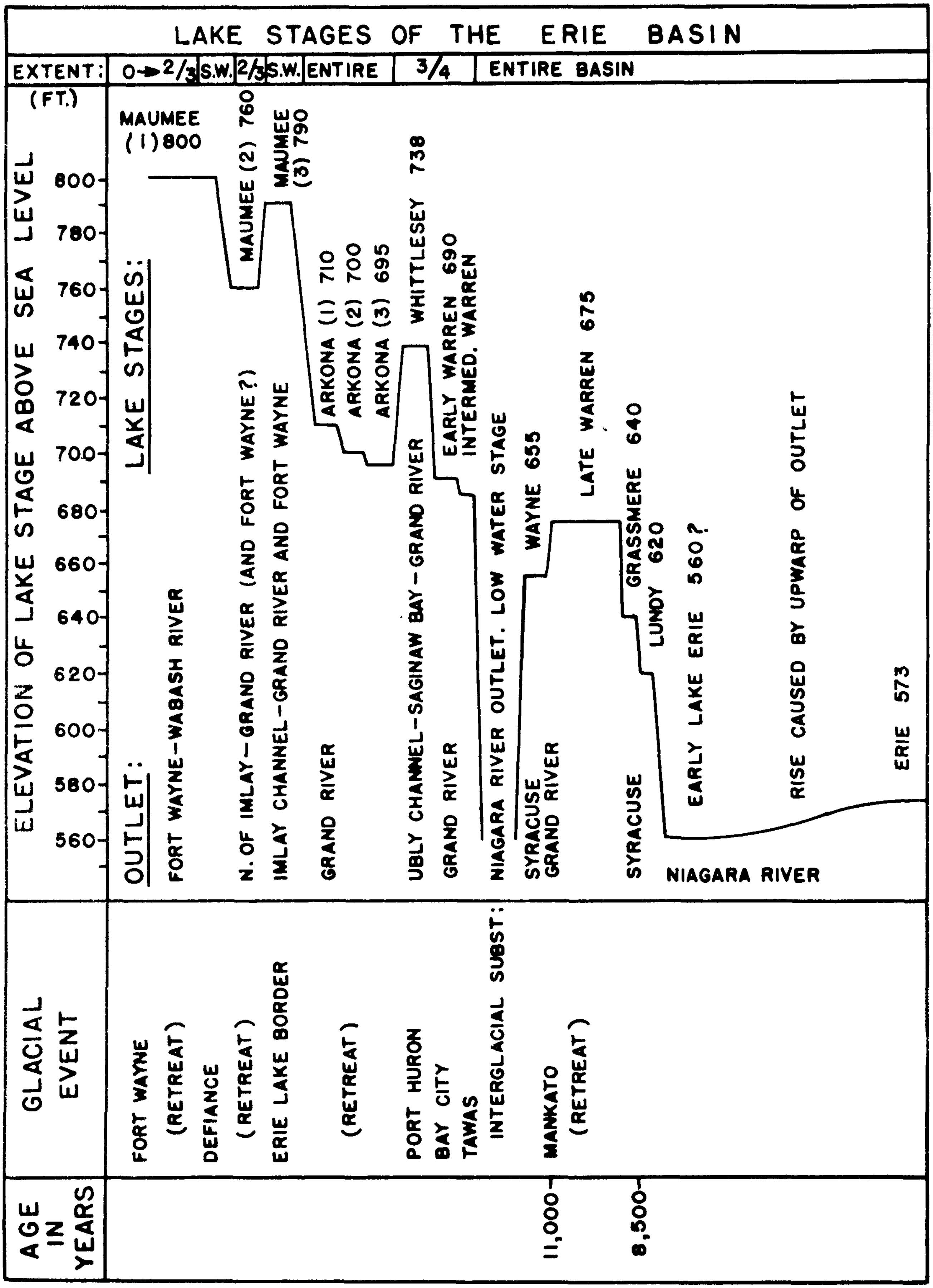

FIG. 2. - Lake stages of the Erie basin.

the Erie basin in post-Fort Wayne--pre-Defiance time, allowing Lake Maumee to expand over a large area, and that fine-grained sediments deposited in the lake were then incorporated into the Defiance till deposited by the next advance of the ice.

The highest Maumee level evidently was maintained during the next ice retreat (from the Defiance moraine), until a lower outlet across the "thumb" of Michigan was uncovered by recession of the ice, because a Highest Maumee level beach occurs on the inside of the Defiance moraine in Michigan.

<u>Second, or lowest, Lake Maumee</u>. - The next definite stage of the lake, the second or Lowest Lake Maumee, is recorded by a beach at an average elevation of 760 feet. This beach has been found at many places along the southern margin of the Erie basin in Ohio and along the northwestern margin of the Erie basin in Michigan. Second Maumee came into existence when the ice front, retreating from the Defiance moraine, receded down the northeast slope of the "thumb" of Michigan (between southern Lake Huron and Saginaw Bay) to a point a little beyond Imlay, and uncovered an outlet which permitted the lake to drain down to an elevation of 760 feet (fig. 13). During this time of recession a large part of the Erie basin was ice-free, but no lake existed as yet in the Huron or Saginaw Bay areas. Lake Maumee drained along the margin of the ice in the Saginaw Bay area, to the Grand River (Bretz, 1951a), and it is possible that a part of the Lower Maumee water drained through the Fort Wayne outlet, because the present elevation of that outlet floor is about 757 feet A.T. (Leverett, 1902, p. 712).

<u>Third, or Middle, Lake Maumee</u>. - During the next advance of the ice, which built the Erie Lake Border moraines of the eastern part of the

southern shore of the Erie basin, the ice advanced up the slope of the "thumb" of Michigan, over-riding the second Lake Maumee outlet, and built the Flint moraine. This advance raised the level of the discharge to about 790 feet. The discharge developed a channel which has been mapped and described as the Imlay channel. In this way, the third or Middle Lake Maumee came into existence at an elevation of 790 feet (fig. 14). Water continued to discharge along the ice-front and down the Grand River, but this lake also discharged water through the old Fort Wayne outlet and down the Wabash River. That Middle Lake Maumee is a younger, third stage which followed Lower Maumee is shown by the washed or submerged character of the Lower Maumee beaches.

Early Lake Saginaw. - During the retreat of the Lake Border ice, the first lake appeared in the Saginaw Bay area. The lake stages of Saginaw Bay and of the Huron basin are shown graphically in figure 3. Early Lake Saginaw, which formed a beach, stood at an elevation of 730 feet during a time of minor fluctuations of the ice front (retreat from the Owosso moraine, advance to the Henderson moraine, retreat, and advance to the West Haven moraine). The outlet channel was not lowered appreciably by erosion during this stage because the channel was clogged by a considerable valley train of Owosso age, brought into the Glacial Grand River below the lake outlets, and because low places in the Owosso moraine provided three outlets, all of which continued to function until the valley train had been sufficiently cleared away to allow downcutting of the channel to take place (Bretz, 1951a); also, because the entire discharge of Third Lake Maumee did not pass through this discharge system.

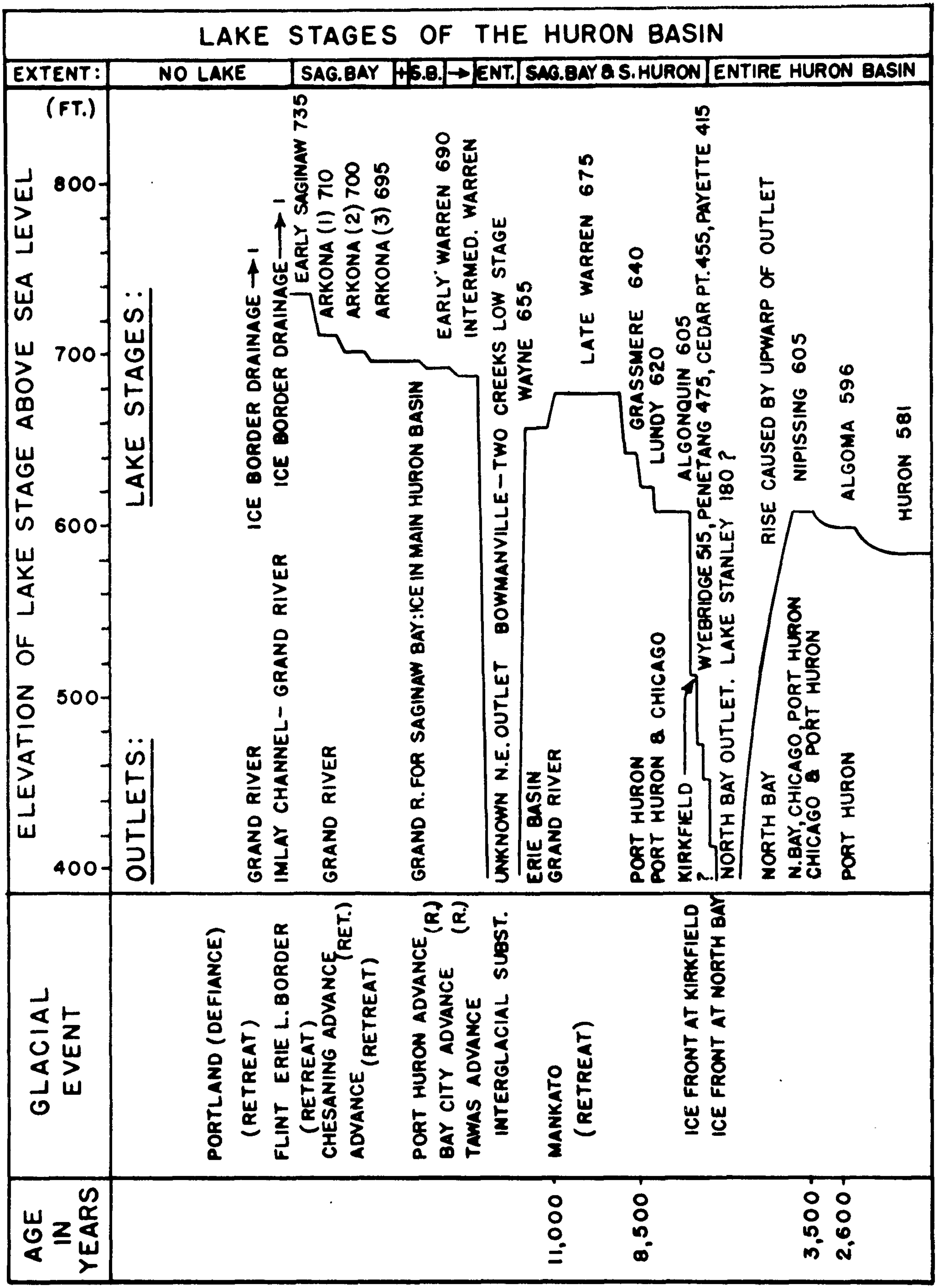

FIG. 3. - Lake stages of the Huron basin.

Later Lake Saginaw. - During the retreat from the West Haven moraine in the Saginaw Bay area, increased discharge from the melting ice began cutting the outlet channel down to the level of Later Lake Saginaw at 710 feet, and the lake in the Erie basin was lowered from the last Maumee level to the first Arkona level, as described below.

Lake Arkona. - The retreat of the ice which allowed the formation of Early Lake Saginaw coincided with the retreat from the Erie Lake Border moraines of Ohio. In the Erie basin the lake waters expanded over the entire basin and into the southern part of the Huron basin; the removal of the ice barrier from the "thumb" of Michigan allowed this entire sheet of water to drain down to the level of the head of the Grand River channel, at an elevation of 710 feet, or to the level of Later Lake Saginaw (fig. 15). This stage of the lake, highest Arkona (the equivalent of Later Lake Saginaw), was dammed east of the Erie basin by the ice front where it lay on high ground in New York, south of the Lake Ontario basin. The Ontario basin was still filled with glacial ice.

Lake Arkona stood for a time at each of three levels, 710, 700, and 695 feet, while continuing to discharge down the Grand River. The static stage at 710 feet is correlated with the minor ice advance which built the Chesaning moraine in the Saginaw Bay area, and the lowering to the next level through downcutting of the outlet is correlated with ice retreat which delivered an increased amount of glacial melt water. The static stage at 700 feet is correlated with another minor advance (represented by the moraine north of Chesaning), and the lowering to the next level, 695 feet, is correlated with ice retreat which again delivered an increased amount of melt water and caused further downcutting of the outlet channel. The next ice advance was a major one, to the main Port Huron moraine. During this advance the lake level in Saginaw Bay remained at 695 feet but a new, higher stage was produced in the Erie basin. The detailed correlations of the lake stages in Saginaw Bay with time of ice advance are those of Bretz (1951a).

Lake Whittlesey. - The advancing Port Huron ice rode up the "thumb" of Michigan to Ubly, separating the waters of Saginaw Bay from those to the east and south, and raising the level of the latter to the Whittlesey stage (fig. 16). Lake Whittlesey stood at an elevation of 738 feet, in the Erie basin, and drained across the "thumb" of Michigan, through the Ubly channel to Lake Saginaw. Lake Saginaw continued to discharge down the Grand River to Lake Chicago. The Whittlesey beach is one of the strongest and best developed in the Great Lakes region. This may imply that it was formed by a lake which occupied one level for a long time, but the fact that the beach was built by a rising lake must be considered also. Various writers have stated that stronger beaches are formed by an encroaching lake, which sweeps shore debris up the slope, than by a lowering lake, which leaves shore debris behind as the water recedes.

Extent of the Port Huron glacier during Lake Whittlesey time. - The main Port Huron ice advance dammed Lake Whittlesey in the northeastern part of the Erie basin and at the southern end of the Huron basin, and it formed the northeastern shore of Lake Saginaw. It built a massive moraine across the upper part of the lower peninsula of Michigan, and it extended approximately half way down the Lake Michigan basin (fig. 16). The actual tracing of this moraine between the lake basins provides the first definite correlation of events in the Michigan, Huron and Erie basins.

<u>End of Lake Whittlesey</u>. - Retreat of the ice from the main Port Huron stand removed the ice barrier from the "thumb" of Michigan and Lake Whittlesey drained down to the level of Saginaw Bay, 43 feet lower (fig. 17). The increased discharge delivered by the lowering of Lake Whittlesey and the increase in amount of glacial melt water during the ice retreat caused a downcutting of the Saginaw-Grand River outlet, lowering the lake level to 690 feet. The total lowering from the Whittlesey level to the new level in Saginaw Bay was 48 feet. This episode in the Erie-Huron basin is correlated with, and is considered the cause of, the downcutting of the Chicago outlet from the Glenwood to the Calumet level. Downcutting of the outlets of both Saginaw Bay and Lake Chicago probably ceased when the Lake Whittlesey drainage was completed.

<u>Early and Intermediate Lake Warren</u>. - Early Lake Warren, at the 690 foot level, existed in both the Erie and Saginaw basins during the building of the Bay City moraine (fig. 17). An intermediate stage of Lake Warren, represented by a weak discontinuous beach, next occurred at an elevation of 682 feet. The lowering to 682 feet is correlated with the ice retreat from the Bay City moraine, and the stand at the 682 foot level is correlated with the advance to the Tawas (or latest Port Huron) moraine (Bretz, 1951a). Intermediate Lake Warren continued to discharge down the Grand River. Retreat of the ice from the Tawas moraine, with increased discharge of melt water, probably caused further downcutting of the Grand River outlet, to the next lowest lake level, 675 feet, but the next lake stage is placed at a much lower level because of the intervention of an interglacial substage following the Port Huron series of

ice advances.

<u>Low Stages during the Two Creeks interval</u>. - The significance of the Two Creeks interval was discussed in the history of the Lake Michigan basin. It was indicated that the water level in the Huron basin must have been at least as low as 580 feet A.T., in order to permit the Lake Michigan waters to drain to that level. Because various lines of evidence suggest a general deglaciation during the Two Creeks interval, with the St. Lawrence valley being freed of ice, it is probable that extremely low stages occurred in the Huron and Erie basins (fig. 18).

It appears reasonable to assume that Lake Erie drained down to the level of the lowest possible outlet which would be exposed if glacial ice were absent from the region; this would be a dischargeway across the Niagara escarpment at the northeastern end of the Lake. A drift-filled portion of the Niagara gorge is considered to represent the outlet channel at the Two Creeks interval Lake Erie low stage. This drift-filled valley extends from the Whirlpool section of the present gorge northwestward to a reentrant of the Niagara escarpment south of St. David. On the maps of the Niagara folio (Kindle and Taylor, 1913) it is labelled a "buried pre-Wisconsin gorge," and it is characterized in the text of the Folio as "interglacial" because of its close similarity to the present Niagara gorge. The Niagara Falls moraine, which lies south of the gorge, is described as the location of the ice barrier of Lake Warren (figure 9 of the Folio). The present writer suggests that the buried portion of the Niagara gorge was cut during the Two Creeks interglacial substage, and that it was filled with drift during the subsequent advance to the Niagara Falls moraine, in Mankato time.

A hypothetical low level lake in the Huron basin during the Two Creeks interval might have discharged down the Trent valley to the Ontario basin, or down the Mattawa-Otawa valleys to the St. Lawrence valley, depending upon the relative elevations of the divides.

Lake Wayne and the Mankato glacial advance. - The Lake Wayne beach, at an elevation of 655 feet A.T., "shows clear evidence of submergence and modification, and the Warren beach does not. It seems, therefore, that the Wayne beach was submerged and modified during the time of Lake Warren" (Leverett and Taylor, 1915, p. 386). From the above description, the Wayne beach must be older than the latest Warren beach, in order to have been submerged; but it is not necessarily older than the Early- or Intermediate Warren beaches, and the writer considers the Wayne stage as probably post-Intermediate Warren and pre-Late Warren.

The Wayne stage occurred sometime between the Port Huron and the Mankato glacial maxima, and the writer tentatively places it in the time of the Mankato advance, after the hypothetical lower stage and thus after the time of cutting of the first (buried) Niagara gorge.

Lake Wayne existed in the Erie basin, in the southern part of the Huron basin, and in Saginaw Bay (fig. 19). The discharge of Lake Wayne is believed to have been eastward to the Mohawk Valley through some of the channels south of Syracuse, N. Y. (Leverett and Taylor, 1915, p. 386).

Late Lake Warren and the Mankato glacial maximum. - When the advancing Mankato ice reached its greatest extent in the eastern part of the Great Lakes region it dammed the eastern outlets of the Huron and Erie basins, and raised their waters to the Lake Warren level, at 675 feet A.T. (fig. 20). This Late Warren stage lake spilled down the old Grand

River outlet, which had been abandoned during the retreat of the last Port Huron ice, and thus discharged its water to Lake Chicago.

The position of the ice front in the Erie and Huron basins during the Mankato maximum is unknown. The ice front certainly was south of Lake Ontario, where it formed the dam of Late Lake Warren. The Niagara Falls moraine probably marks the position of the Mankato ice border between the Ontario and Erie basins. From there the border extended northward around the high ground between the Ontario and Huron basins, along the Gibraltar moraine (Chapman and Putnam, 1951, p. 31). The margin of the Mankato ice probably stood well out in the lake in the Huron basin, and crossed the western shore somewhere north of Saginaw Bay. The extent of the ice in the Michigan basin has been described in an earlier section of the report.

During the early stage of retreat of the Mankato ice, the Late Warren lake stage would have persisted until a lower outlet was exposed to the east. The discharge of the lake down the Grand River, meanwhile, would have been augmented by a greater volume of melt water, and this increased discharge may be the factor which is mainly responsible for the downcutting of the Chicago outlet and the lowering of Lake Chicago from the Calumet to the Toleston stage (fig. 21).

Lakes Grassmere and Lundy. - The Grassmere beach at an elevation of 640 feet and the Lundy beach at 620 feet record two static periods during the lowering of the Huron and Erie basin waters. Both of those levels are below the sill of the Grand River outlet, and Lakes Grassmere and Lundy must have discharged to the eastward through outlets uncovered by the retreating Mankato ice (fig. 22).

Wood from Lake Grassmere deposits at Bellevue, Ohio, has been dated by the radiocarbon method and found to be 8513 ± 500 years old (Libby, 1951).

Detailed studies in the Detroit area have shown that during Grassmere time the waters of the Lake Huron and Lake Erie basins were connected by a shallow strait. When the water in the Erie basin dropped to the Lundy level the Huron basin water flowed for a brief time with a strong current over the top of the main Port Huron moraine, at St. Clair, Michigan, to deepen the shallow strait and bring the waters to the same level in the Huron and Erie basins, and then the Lundy stage existed in both Lake basins (Leverett and Taylor, 1915, p. 399).

Later lake stages in the Erie and Huron basins. - At the close of Lundy time, when the water in the Erie basin fell lower (because of drainage through a lower outlet to the east), the lake in the Huron basin was left at a higher elevation. The discharge from the Huron basin to the Erie basin apparently deepened the outlet channel rapidly while the water surface in the Huron basin was lowered from the Lundy level (620 feet) to an elevation of 605 feet, because no beach deposits are found in the interval between these levels. The new level in the Huron basin, 605 feet, is marked by the strong Algonquin beach. The outlet channel obviously must have become stabilized to hold the lake at the Algonquin level, and to carry the maximum discharge from the Huron and Michigan basins throughout Algonquin time.

Further discussion of the Algonquin and later stages in the Huron basin will be given in another section of the report.

The Erie basin waters by this time were separated from the other lake basins, and the name "Lake Erie" may appropriately be applied. This early Lake Erie undoubtedly discharged over the Niagara escarpment and began cutting the modern Niagara gorge. It probably stood at an elevation lower than that of the present lake, because upwarp of the land to the northeast has taken place since the first separation of Lake Erie from the other lakes.

Lake Stages in the Superior Basin

The record of lakes begins much later in the Superior basin than it does in the Michigan, Erie and Huron basins, because glacial ice occupied the more northern parts of the region for a longer time.

Two Creeks interval lake. - Because the red till which is peripheral to the Superior basin is correlated with the red till of the Michigan basin, it is apparent that Mankato ice completely filled the Superior basin (fig. 20). This ice advance very likely destroyed all traces of beach deposits which would have been formed by pre-existing lakes. The presence of a lake in the Superior basin during the Two Creeks interglacial substage has been inferred, however, from the postulate that the red till is red because it contains reworked red lake clays and silts. This point is discussed in greater detail in the section of the report dealing with the Lake Michigan basin. The inferred interglacial substage lake is included on the diagram of figure 4, which gives the lake stages of the Superior basin, and it is shown on the map, figure 18.

Lake Duluth. - When the Mankato ice began its retreat from the southwestern end of the Superior basin, water was impounded between the ice front and the morainic divide to the southwest, forming Lake Duluth (fig. 22). This lake discharged through an outlet near Brule, Wisconsin, and down the St. Croix River to the Mississippi River. Several stages of Lake Duluth are recorded by beaches which have been traced in the southwestern third of the basin. The highest recorded stage was at an elevation of 1100 feet A.T. in western Douglas County, Wisconsin, near the outlet. Three successively lower stages are recorded by beaches at elevations of 1076, 1044 and 1022 feet, in the vicinity of the outlet. These three

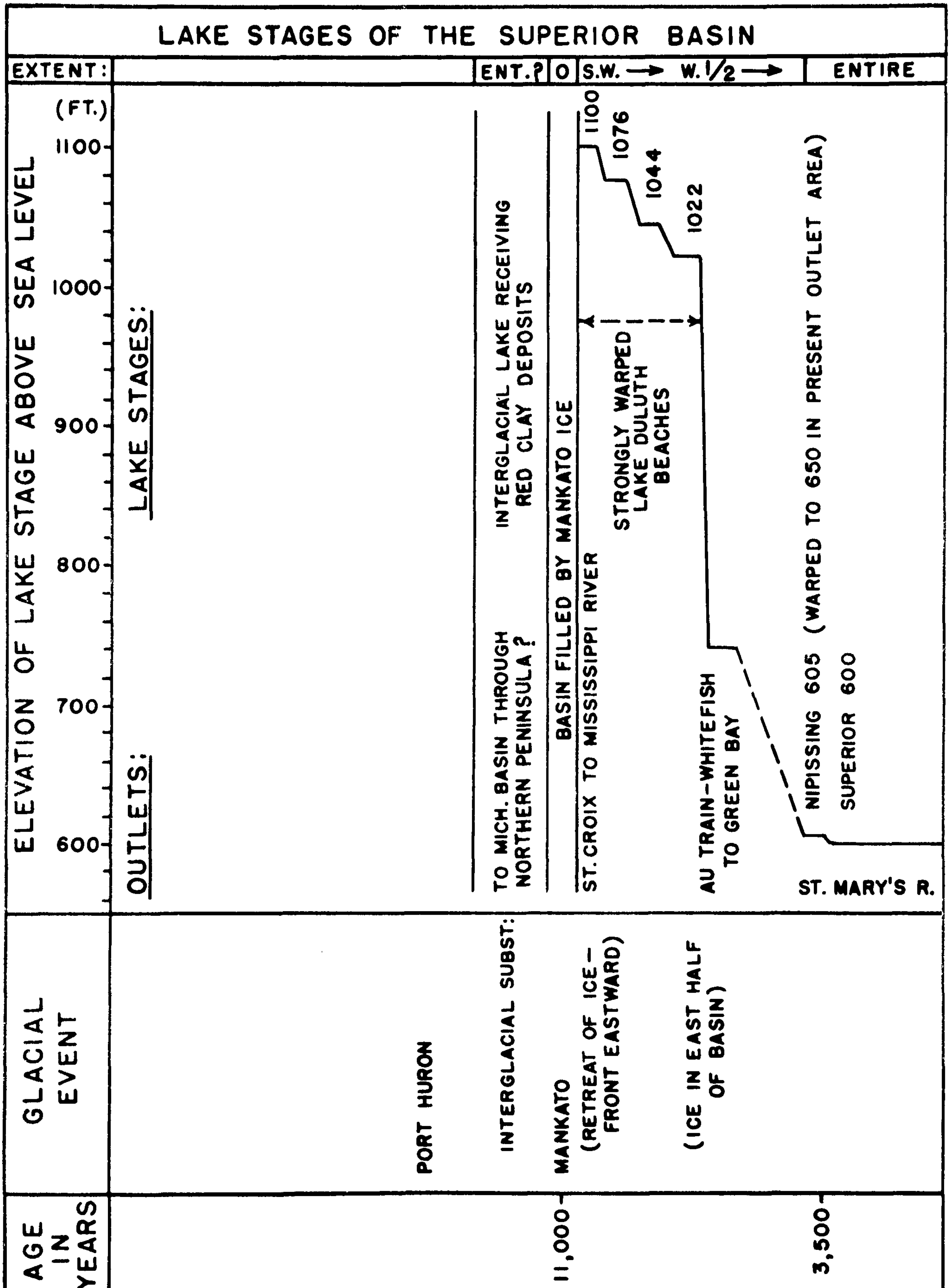

FIG. 4. - Lake stages of the Superior basin.

beaches have been traced eastward for some distance along the south side of Lake Superior, but their correlatives to the east are difficult to determine. Northeastward along the northern side of the Superior basin the three beaches have been traced as far as Grand Marais, Minnesota, and in this tracing they have been found to rise strongly to the northeast (Leverett, 1929). The highest beach at Grand Marais is at an elevation of 1275 feet. From elevations given by Leverett, it is apparent that the three beaches remain essentially parallel with each other in their rise to the northeast, and because of this it may be inferred that upwarp of the land occurred after the lowest beach of this series was formed.

The highest beach in the vicinity of the outlet, at 1100 feet, is a faint one and it has not been recognized beyond a distance of 40 miles from the southwestern end of Lake Duluth. This suggests that the outlet channel of the lake was lowered, and the next lower lake stage came into existence, early in the life of Lake Duluth before the ice front had receded very far to the northeast. The next three stages apparently continued to discharge through the outlet to the St. Croix River, because the floor of the outlet is at an elevation of 1022 feet. All later, lower stages must have discharged elsewhere.

Beaches formed during lower stages of Lake Duluth are found in abundance along the western part of the south shore of the basin as far eastward as the Keweenaw Peninsula, and a few distinct strand lines are present from there eastward to the vicinity of Marquette, Michigan. The sequence of events and the causes for different lake stages in the Superior basin have not been worked out in detail.

It is apparent, however, that Lake Duluth discharge must have abandoned the St. Croix outlet after the retreating ice front exposed the lower slopes of the Huron Mountains west of Marquette and when the ice retreated from the AuTrain-Whitefish lowland, exposing a dischargeway to Green Bay in the Lake Michigan basin (fig. 24). This occurred after the highest Algonquin stage had existed in the lower lake basins (refer to the discussion of Lake Algonquin in a later section of this report).

It is possible that the Superior basin waters next discharged to the Michigan basin through lower channels across the peninsula in the Taquamenaw River-Manistique River area, but this possibility has not been developed in the literature. The final route of discharge was taken when the glacial ice receded from the southern shore (fig. 25).

The later lake stages of the Superior basin will be discussed in later sections of the report.

Lake Stages in the Ontario Basin

The history of lakes in the Ontario basin is not well established at the present time, and no attempt is made in the present report to evaluate the available data. It is understood that studies being made by the Canadian Geological Survey have a bearing on the Pleistocene and Recent history of the Ontario basin and the St. Lawrence valley. A few major events in the Ontario basin may be inferred from the history of the upper lake basins.

The Two Creeks interval. - The Ontario basin and at least a portion of the St. Lawrence Valley apparently were free of ice during the Two Creeks interglacial substage (fig. 18), as stated in the discussion of the Lake Michigan basin. If it may be assumed that the lands of this area were depressed, we may assume that an embayment of marine water existed at this time.

The Mankato glacial advance. - The subsequent advance of the Mankato ice to dam Late Lake Warren south of the Ontario basin probably filled the Ontario basin completely (fig. 20). The Niagara Falls moraine apparently marks the Mankato margin near the western end of the basin. Any shore deposits made by pre-Mankato lake or marine stages would have been over-ridden by the Mankato ice.

Post-Mankato lake and marine stages. - There is a definite record of lakes in the Ontario basin in post-Mankato time, consisting of well developed strand lines of Lake Iroquois, and there is a record of a marine embayment following the freshwater stages (Leverett and Taylor, 1915, pp. 325-326, 444-446).

Because the present report contributes little to the history of the

Ontario basin beyond pointing out the significance of the Two Creeks interglacial substage, no further discussion of the Ontario basin is given here. The inferred events in the Ontario basin are shown on the maps of figures 11-26.

Lake Algonquin

The Algonquin stage existed in the basins of both Lake Michigan and Lake Huron, following the Toleston and the Lundy stages which have been described in previous sections of this report.

The establishment of Lake Algonquin. - After the waters of Lake Lundy (fig. 22) were lowered in the Erie basin, and the Port Huron outlet channel was lowered to a gradient adjusted to the barrier at Trenton, the lake in the Huron basin stood at the Algonquin level, 605 feet. There is a single well-developed beach in many parts of the Huron and Michigan basins at about 605 feet. There is no beach above this level for 15 feet and this indicates that the drop to the Algonquin level was rapid.

Taylor (Leverett and Taylor, 1915, pp. 409-413) described several introductory stages of Lake Algonquin, including a Kirkfield stage, at an elevation 50 to 100 feet below the highest Algonquin level, when discharge was through an outlet at Kirkfield, Ontario, southeast of Georgian Bay. He believed that Lake Toleston in the Michigan basin may have joined with the lake in the Huron basin during the Kirkfield stage. The lake was then raised back to the Algonquin level by upwarp of the Kirkfield outlet. Taylor stated: "These steps of transition are mainly matters of inference and are not based on observation" (Leverett and Taylor, 1915, p. 409).

Stanley (1936) has since demonstrated that no appreciable upwarping took place until much later in the lake history. Taylor's hypothetical early stages of Lake Algonquin must, therefore, be rejected. The Kirkfield outlet was used much later, at the termination of the Algonquin stage.

According to the present interpretation Lake Algonquin came into existence at the 605 foot elevation, and remained at that level for a considerable period of time. During this first, highest, Algonquin stage the ice retreated from the lowland east of Little Traverse Bay and allowed Lake Toleston in the Michigan basin to join with the lake in the Huron basin (fig. 23). Apparently it was a coincidence that the two lakes stood at approximately the same level before they were joined. That they did stand at nearly the same level is indicated by the fact that there is a single strong beach at elevation 605 feet in both the Huron and Michigan basins, and there is no beach above this level for 15 feet. Highest Lake Algonquin discharged through both the Chicago and Port Huron outlets throughout its existence. The Chicago outlet had been used by Lake Toleston, and was still available for use by Lake Algonquin which stood at essentially the same level. The Port Huron outlet must also have been low enough to discharge water at this stage, or it would have been abandoned and could not later have become the sole outlet.

<u>The Algonquin beach on the east side of the Huron basin</u>. - The Algonquin beach extends from Port Huron northeastward to Grand Bend, Ontario (a distance of 40 miles) at a uniform level about 25 feet above the present Lake Huron. From Grand Bend north to Kincardine (a distance of 60 miles) erosion at the level of the present lake has removed any higher beaches which may have existed (Leverett and Taylor, 1915 Pl. XXV). Higher beaches occur at various points from Kincardine northeastward along the Huron shore to Southampton, and northeast of there in the southern part of Georgian Bay. The highest of these beaches is identified as the Algonquin, and it occurs at successively higher elevations toward the northeast (because of post-Algonquin tilting) to Kirkfield, Ontario. The elevations of the highest beach found northeast of Kirkfield show that it lies in a plane

below that of the Algonquin (Goldthwait, 1910, p. 31). Lake Algonquin, at its maximum extent at the original highest level, extended only as far as Kirkfield in this part of the Huron basin, and it must have been dammed by glacial ice which covered the Kirkfield outlet and the land to the north (fig. 23).

The highest Algonquin beach is not known to exist anywhere on the eastern or northern shores of the Huron basin, between Kirkfield, Ontario (east of the south end of Georgian Bay), and the vicinity of Sault Ste. Marie. It is very likely that the northeastern shore of the lake was formed by the glacier margin which stood in the lake throughout this area in highest Algonquin time.

The Algonquin beach on the west side of the Huron basin. - A well developed highest Algonquin beach has been traced from Port Huron northward along the west side of the Huron basin to the northern end of the southern peninsula of Michigan (Leverett and Taylor, 1915, pp. 416-422). The beach is missing where the present lake has cut the shore strongly, but apparently the highest Algonquin beach has been correctly identified throughout this stretch of the lake basin. This beach is horizontal at an elevation of about 605 feet from Port Huron north to Port Sanilac. It occurs at an elevation of 615 feet at the northern end of the thumb of Michigan, near Point Aux Barques, and descends southwestward around the head of Saginaw Bay to an elevation of about 605 feet. From Saginaw Bay northward the beach occurs at progressively higher elevations, and reaches a level of 741 feet at Rogers City near the northeast shore of the southern peninsula of Michigan. This rise of the beach to the north indicates that the land has been warped up to the north since the beach was formed.

From Rogers City the highest Algonquin beach extends westward through a lowland to Petoskey, on the Little Traverse Bay shore of Lake Michigan.

Archipelago north of Little Traverse Bay. - When the ice front first retreated from the lowland between Little Traverse Bay and the Huron basin on the east, allowing the waters in the Michigan and Huron basins to be connected, Lake Algonquin occupied both lake basins. While the ice front retreated farther northward, and before the highest Algonquin stage was ended by drainage through a new lower outlet east of Georgian Bay, highest Lake Algonquin expanded northward. The highest Algonquin beach has been recognized on the slopes of several areas of high ground between Little Traverse Bay and the Straits of Mackinac. Several islands of various sizes existed in this area (Leverett and Taylor, 1915, pp. 423-424). The elevation of the beach at Cross Village, 18 miles north of Petoskey, is 746 feet. Mackinac Island, in Lake Huron at the eastern end of the Straits of Mackinac, carries the highest Algonquin beach at an elevation of 809 feet (Leverett and Taylor, 1915, pp. 425-431).

Northernmost extent of Lake Algonquin. - The northern peninsula of Michigan between the Straits of Mackinac and the St. Mary's River is generally lower than the present elevation of the plane of the Algonquin beach, but the beach has been identified on a few higher parts of the area. The northernmost beach which can reasonably be correlated with Lake Algonquin occurs six miles north of Sault Ste. Marie, Ontario, on the edge of a crystalline rock upland, at an elevation of 1015 feet. From this point southward toward the Straits of Mackinac the altitudes of the highest beaches are at progressively lower elevations and lie in a plane, or slightly curved surface, which indicates that all of the beach elevations were originally formed at the same level and were subsequently warped to their present positions. The highest Algonquin beach on St. Joseph Island, 20 miles south of Sault Ste. Marie, is at an elevation of 930 feet. The surface of a glacial outwash plain at Rexford, Michigan, on the peninsula 35 miles west of St. Joseph Island, is also at an elevation of 930 feet. The Algonquin beach has not been found east of St. Joseph Island, probably because the front of the receding glacier stood in the lake to the east, and extended through the Huron basin to the southeastern shore as previously described. The extent of Lake Algonquin west of Sault Ste. Marie will be discussed after the beach in the Lake Michigan basin has been described.

Lake Algonquin in the Michigan basin. - The highest Algonquin beach has been traced from Petoskey on the south side of Little Traverse Bay, southwestward with progressively lower elevations until it was found at an elevation of 619 feet at Traverse City, Michigan. In the area between Petoskey and Traverse City the beach occurs on the sides of the valleys of many inland lakes and around the shore of Grand Traverse Bay. From Traverse City to Frankfort, discontinuous beaches correlated with the Algonquin beach permit its tracing down to the 605 foot level. From Frankfort southward to the south end of the Michigan basin the highest Algonquin beach is horizontal at an elevation of 605 feet, and coincides with the Toleston beach, its predecessor in this basin. The horizontality of this beach indicates that no warping has taken place south of Frankfort (Leverett and Taylor, 1915).

From Chicago northward along the west side of the Michigan basin to Two Rivers, Wisconsin, the beach maintains an elevation of 605 feet, except where it is missing because of erosion during later lake stages.

From Two Rivers northward the beach rises and it occurs at an elevation of 723 feet at Burnt Bluff, Michigan, on the south end of the peninsula which separates northern Green Bay from Lake Michigan (Goldthwait, 1907).

Northern shore of Lake Algonquin in the Michigan basin. - Lake Algonquin extended into or completely occupied the Lake Superior basin, according to Leverett and Taylor (1915) and Leverett (1929). This concept is rejected in the present revision of the lake history, and the northern shore of Lake Algonquin is placed on the Northern Peninsula of Michigan from the head of Green Bay to Nadoway Point, about 15 miles west of Sault Ste. Marie, Ontario (fig. 23).

The reasons which lead early investigators to believe that Lake Algonquin occupied the Superior basin are the following: Coleman (1909) found gravelly ridges east of Lake Superior in the area north of Michipicoten Bay at elevations up to 1400 feet. These lay close to a northward projection of the Algonquin water plane. On McKay Mountain, south of Fort William, Ontario (northwest shore of Lake Superior), indications of lake action were found up to 1350 feet, and high beaches were found on the Keweenaw Peninsula (Leverett, 1929). All of these observations were plotted on an isobase map for the Great Lakes region and appeared to represent points in a warped Lake Algonquin plane. That hypothetical plane passes above almost the entire area of the peninsula of Michigan which separates the Michigan and Superior basins, and the boundary of Lake Algonquin was therefore drawn around the Superior basin. Having concluded that Lake Algonquin existed in the Superior basin, Leverett and others assumed that some of the beach features found there represented Algonquin shores. The gravel deposits reported by Coleman need be given little attention in connection with the Lake Algonquin problem. The writer has observed many other gravel and sand deposits in the area east of Lake Superior, and judges them to be unrelated to Lake Algonquin. The beaches near Fort William and on the Keweenaw Peninsula are more certainly related to Lake Duluth than to a possible Lake Algonquin.

Leverett's (1929) strongest statements supporting the existence of Lake Algonquin in the Superior basin are quoted below, with italics by the present writer:

"There are so few data available on the Lake Algonquin shore lines in the Canadian part of the Lake Superior Basin that it can not be adequately treated at this time" (p. 66).

"In the northern part of the northern peninsula there are half a dozen or more distinct shore lines, all referable to Lake Algonquin. At the top of the series are usually two or three ridges that are especially strong and continuous which are separated by intervals of but 5 to 10 feet....the lowest member of this upper series *may be* the one that should be correlated with the single strong beach that leads to the Port Huron outlet and to the Chicago outlet. It *seems probable*, also, that the western part of the Lake Superior Basin had become connected with Lake Algonquin by the time this strong series was completed. On the whole, the Lake Algonquin beaches in the western part of the Lake Superior Basin are weak and widely spaced, as if they might have been formed during the time of rapid uplift.

"The limits of Lake Algonquin are *less definitely known* in the uninhabited districts of northeastern Delta County and adjacent parts of Alger and Schoolcraft Counties, Mich., but *it is thought* that an aggregate area of about 200 square miles in this region may have stood above the

Algonquin level" (p. 66).

"This morainic system [in the eastern part of the northern peninsula of Michigan] is in part above and in part below the level reached by the waters of Lake Algonquin. The part below that level has a much stronger morainic expression than is commonly exhibited by moraines laid down in water, such as those of the Saginaw and Erie Basins. The effect of the [supposed] lake has been remarkably slight in toning down the morainic features. The basins are only partly filled and the knolls bear only slight notches...the moraines are bordered in places [on their south sides] by plains of sandy gravel, which by their situation as well as the character of their material appear to be outwash aprons, yet most of them are considerably lower than the highest level of Lake Algonquin" (p. 49).

Evidence against the existence of Lake Algonquin in the Superior basin is contained in Leverett's (1929) paper, though he did not recognize its significance. The outwash plain with an elevation of 930 feet at Rexford, mentioned in the discussion of the Sault Ste. Marie area, is a part of the evidence. This outwash plain lies along the southeastern border of a glacial moraine, and it presumably was formed in the edge of a body of standing water. That body of water presumably was Lake Algonquin, because the Lake Algonquin level is at 930 feet in this latitude.

The moraine which borders this outwash plain on the northwest has been mapped by Leverett (1929, pl. 1) from Nadoway Point (15 miles west of Sault Ste. Marie) southwestward and westward across the southern part of the peninsula which separates the Superior and Michigan basins. The existence of this moraine with an Algonquin level outwash plain beside it indicates that glacial ice was standing in the Superior basin while the lake to the south was at the Algonquin level (fig. 23).

A second, more northerly, moraine swings away from the southerly one at a point 18 miles southwest of Nadoway Point, extends northwesterly and westerly between Taquamenaw Swamp and Lake Superior, and parallels the shore of Lake Superior from Grand Marais to Munising. A few miles southwest of Munising this moraine swings southward, indicating that a lobe of ice occupied the Au Train-Whitefish lowland between the Superior basin and the head of Green Bay to the south. This more northerly of the two moraines is the one with outwash plains on its south side which are "considerably lower than the highest level of Lake Algonquin" (Leverett, 1929, p. 49). It is suggested here that between the time the ice front stood at the southern moraine and the time of its stand at the northern moraine the level of Lake Algonquin had been lowered below its highest elevation. This probably occurred when the ice front in the Georgian Bay region retreated from the Kirkfield area and opened a lower outlet there.

Leverett cited no evidence for an Algonquin beach on the Lake Superior side of the peninsula, but he does give evidence that the highest lake stage there was considerably lower: "Along the inner slope, on the south shore of Whitefish Bay, the morainic contours extend down within 50 feet of the Lake Superior level, or 650 feet above the sea-." (Leverett, 1929, p. 52). The elevation of the Nipissing beach in the Sault Ste. Marie area 30 miles to the east is 650 feet.

The writer has observed additional evidence, in the Sault Ste. Marie area, that glacial ice stood in the Superior basin at the time of the highest Algonquin stage. The highest beach, identified as Algonquin by earlier workers, is well developed along a portion of the Root River six miles north of Sault Ste. Marie. The beach is recorded not only by a beach form of deposit, but by gravel and sand deltas at the mouths of tributaries of the Root River and at the mouths of other streams to the west. All of these streams are in valleys which extend from the beach, at the south edge of a crystalline rock upland, northward or northwestward across the gently rolling upland to its northern or northwestern edge, overlooking the Lake Superior basin. The valley bottoms are composed of unconsolidated sediments and they have low gradients rising from the Algonquin beach elevation on the south to points two-thirds of the distance to their northern heads. Approximately the northern third of each of these valleys now drains northward to the Superior basin through a higher-gradient, more youthful-appearing stream. This topography is shown on sheet 41 k/9 of the National Topographic Series, Canadian Department of National Defence (1939).

The writer's interpretation of this information is that glacial ice stood in the Superior basin to the north, with its front along the northwestern edge of the highland, on a northeastward extension of the axis of the moraine which extends from the southwest to Nadoway Point. Outwash from this ice filled the lower portions of the valleys, grading them to the level of Lake Algonquin which stood at the southern edge of the highland. The only adequate source of material for grading the valleys in this area at this time is glacial outwash.

The conclusion of the writer is that the northernmost shore of Lake Algonquin extended from the Sault Ste. Marie area southwestward and westward across the head of the Lake Michigan basin to the northern end of Green Bay, and that it did not occupy any part of the Superior basin (fig. 23).

Termination of the Algonquin stage. - The highest Lake Algonquin stage, which has been described in detail, could have been terminated either by downcutting of one of its southern outlets or by the diversion of its discharge to a new, lower outlet made available by recession of the glacial ice dam. Because the Algonquin beach extends from the Port Huron outlet northeastward to Kirkfield, Ontario, and not beyond, it is concluded that ice dammed the Kirkfield outlet during highest Algonquin time and that when the ice front receded from the Kirkfield area, the lake immediately drained eastward through the Kirkfield outlet and was lowered rapidly to a new, lower level. The Port Huron outlet, therefore, apparently was not lowered but was abandoned at the close of highest Algonquin time.

Later "Algonquin" Stages

The highest, or main, Algonquin stage has been described in the preceeding section. Below the highest Algonquin beach in some parts of the warped area there are several strand lines which have been classified as "lower Algonquin" beaches. At Mackinac Island these beaches occur at intervals through a vertical range of 180 feet. The strongest member of this group is the main Battlefield beach, at an elevation of 720 feet (90 feet below the highest Algonquin).

None of these beaches can be traced continuously from location to location, and because of the general lack of distinguishing characteristics they can not be correlated with certainty. Nevertheless, Leverett and Taylor (1915) have concluded that they converge to the southward and join the highest Algonquin beach at the elevation of 605 feet. This interpretation formed the basis for the hypothesis that all of the "Algonquin" beaches were formed during a period of uplift of the land to the north, but that for some reason the uplift ceased at various times when the individual beaches were formed. During the entire time of development of the "Algonquin" series of beaches, the discharge of the lakes must have been to the south through the Port Huron and Chicago outlets, according to this hypothesis.

Later studies by Stanley (1936, 1937) strongly suggest that four prominent "lower Algonquin" beaches in the Georgian Bay area are essentially parallel and not converging to the south. These beaches and their elevations in relation to the unwarped highest Algonquin beach are as follows:

Highest Algonquin beach . . . . 605 feet

Wyebridge beach (-90) 515

Penetang beach (-130) 475

Cedar Point beach (-150) 455

Payette beach (-190) 415

The elevations given in the above tabulation were obtained under the assumption that the beaches are exactly parallel and that they may be projected below the highest Algonquin beach (and thus below the present lake surface in the area of horizontality). The distance of each beach below the highest Algonquin level in the area studied by Stanley was subtracted from the elevation of the highest Algonquin in the area of horizontality. Stanley's Wyebridge beach appears to correlate with the Battlefield beach on Mackinac Island, because both are 90 feet below the highest Algonquin beach.

Stanley has demonstrated that the Nipissing beach, which is younger than the "Algonquin" series and which lies below it in the North, cuts across some of the lower "Algonquin" beaches as it is traced southward. He has interpreted these relationships as an indication that no appreciable warping took place until after the entire "Algonquin" series was formed, and that the successively lower elevations of the water surface were produced by drainage through successively lower outlets uncovered by retreat of the ice east of Georgian Bay (figs. 24, 25).

An inescapable consequence of this hypothesis is that an additional extremely low lake stage may have occurred in the Huron basin after the highest Algonquin stage and before the Nipissing stage. Because a projection of the highest Algonquin plane passes 600 feet above the present elevation (about 600 feet) of the old outlet at North Bay, Ontario, it appears that the ground elevation at the outlet formerly was at or close to sea level. If the ice barrier disappeared from this place before any appreciable upwarp took place, the water in Georgian Bay would have been drained down nearly to sea level (fig. 25). After indicating this possibility, Stanley (1938) described the deep channel through the Straits of Mackinac and suggested that Lake Michigan was drawn down and discharged through this channel to a low-level lake in the Huron basin which connected with the inferred extreme low-stage lake in Georgian Bay.

The work of the present project has substantially confirmed Stanley's hypothesis by finding evidence for a post-Mankato low stage of Lake Michigan at an elevation of 230 feet A.T. The evidence for this low stage will be presented in the following section on Lakes Chippewa and Stanley.

The writer suggests that the terms "later Algonquin" and "lower Algonquin" should no longer be applied to those stages which were below the "highest" or main Algonquin stage. The terms were appropriate under the assumption that all of the stages used the same (southern) outlets, but now that it is obvious that the later stages must have discharged through other, lower, outlets, the name Algohquin should not be associated with the later stages. The writer henceforth will restrict the name "Algonquin" to the stage which previously has been designated as "highest Algonquin."

Lakes Chippewa and Stanley

Lakes Chippewa and Stanley are believed to have existed in the Michigan and Huron basins, respectively, as the lowest stages between Algonquin and Nipissing time (fig. 25). The existence of an extremely low stage in the Huron basin was postulated by Stanley (1936, 1937). Direct evidence for a low stage at elevation 230 feet A.T. in the Michigan basin was obtained in the work of the present project. The existence of this low stage in the Michigan basin requires that the water in the Huron basin was at least as low, and thus Stanley's postulate is supported. The names Chippewa and Stanley are assigned to these two contemporaneous lakes by the writer. The evidence for the existence of Lake Chippewa is presented in the following paragraphs. It is based on the study of 96 core samples taken from the middle third of the Lake Michigan basin, as described in the Introduction of this report.

Deep-water core samples. - All of the core samples taken from depths greater than 348 feet contain more or less complete portions of the same sequence of sediments, and thus establish the widespread existence of a normal deep-water sequence. Logs of eight deep-water cores are given in figure 5, and a diagrammatic summary of all of the deep-water cores is given in figure 8. The deep-water sequence is as follows:

gray lake clay

grading to:

red lake clay

bluish gray clay zone

red lake clay

red glacial till

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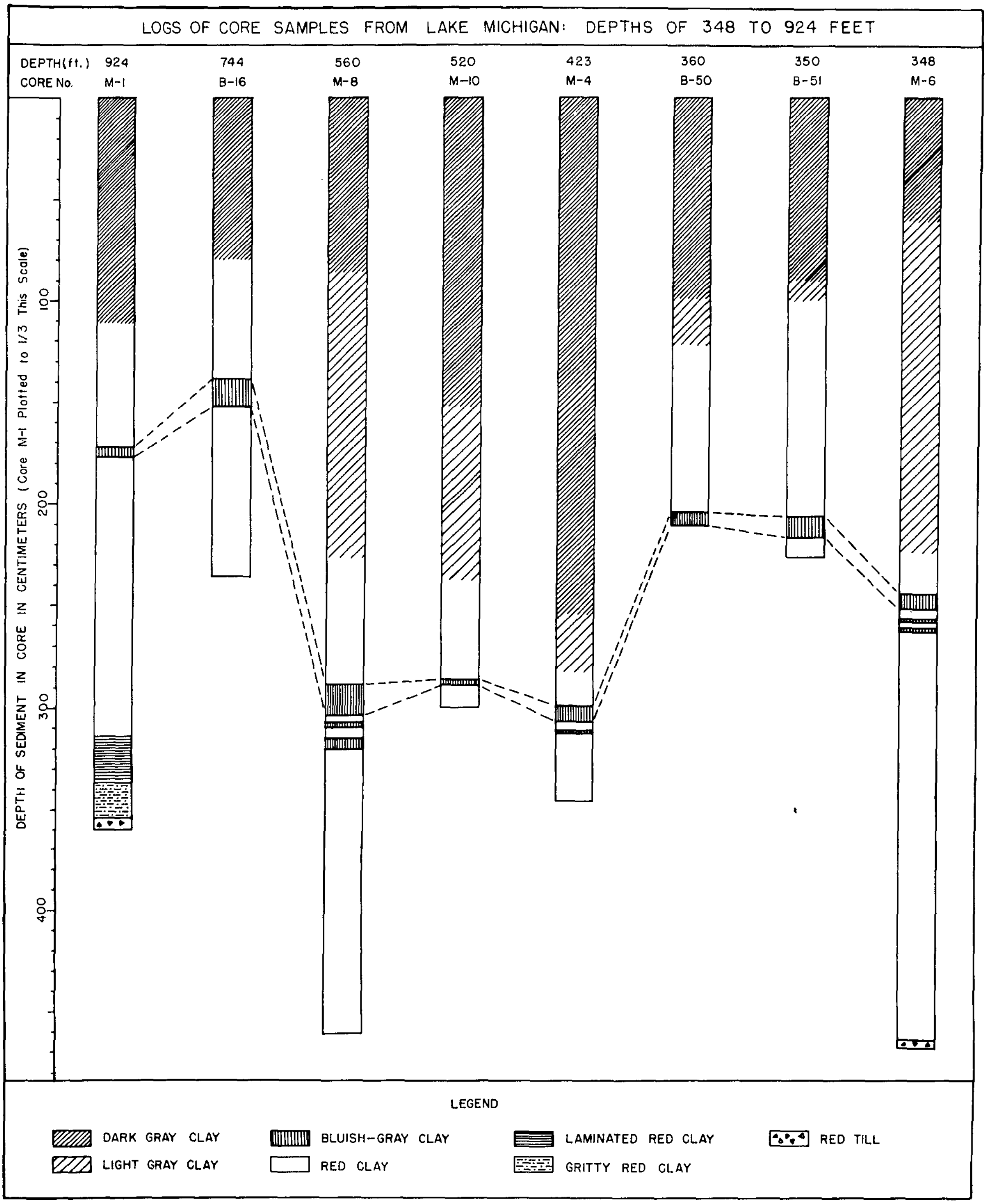

FIG. 5. - Logs of core samples from Lake Michigan: depths of 348 to 924 feet.

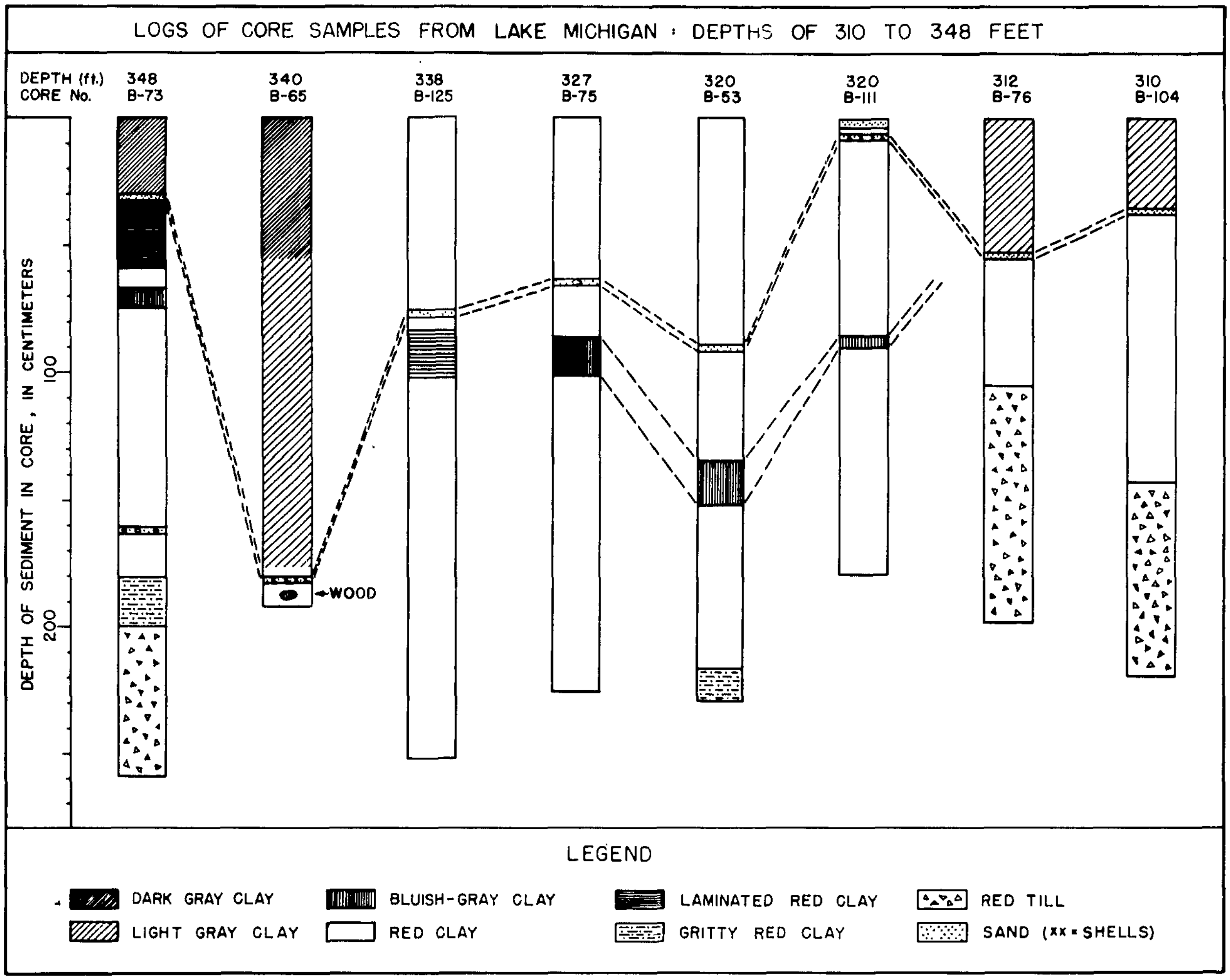

FIG. 6. - Logs of core samples from Lake Michigan: depths of 310 to 348 feet.

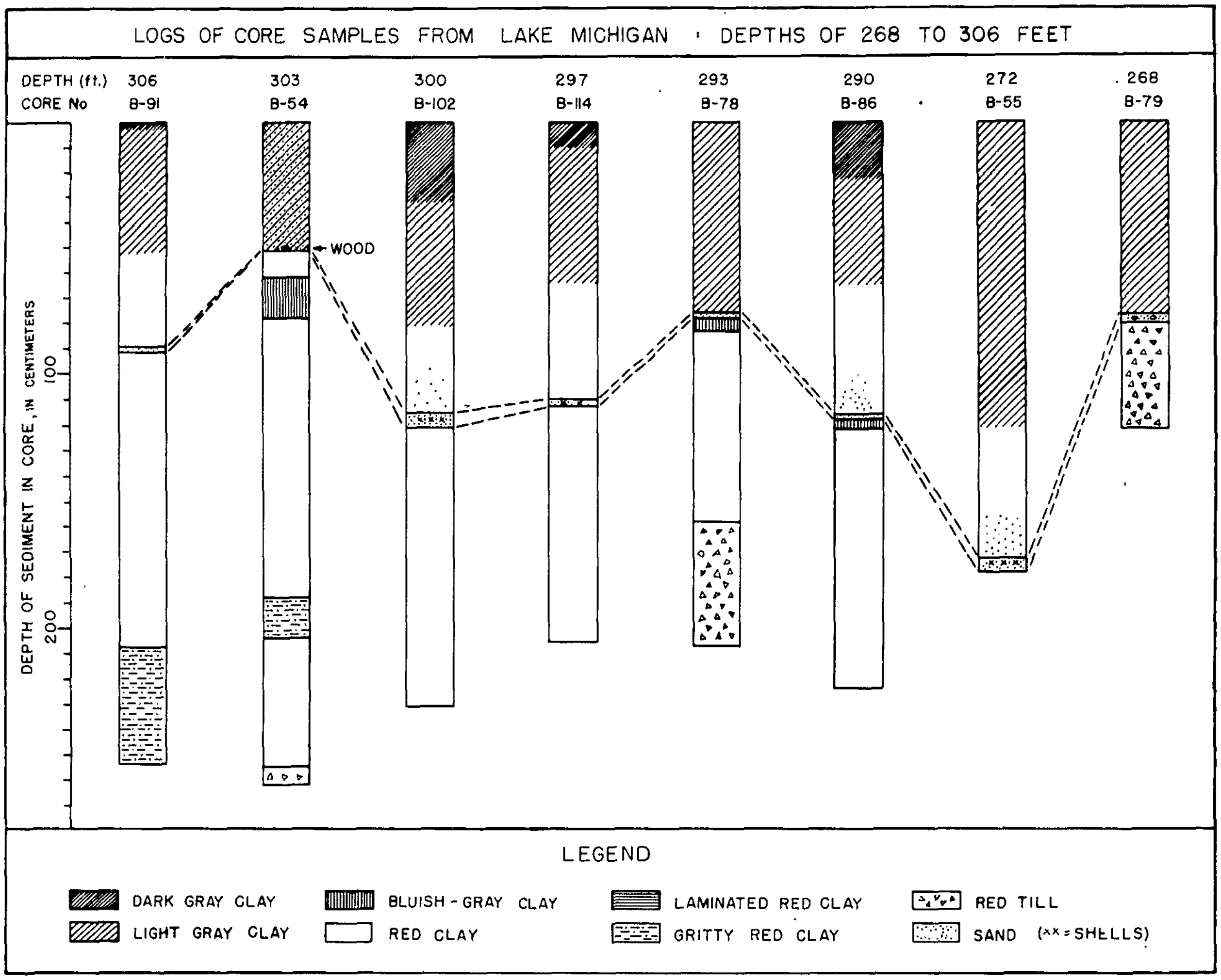

FIG. 7. · Logs of core samples from Lake Michigan: depths of 268 to 306 feet.

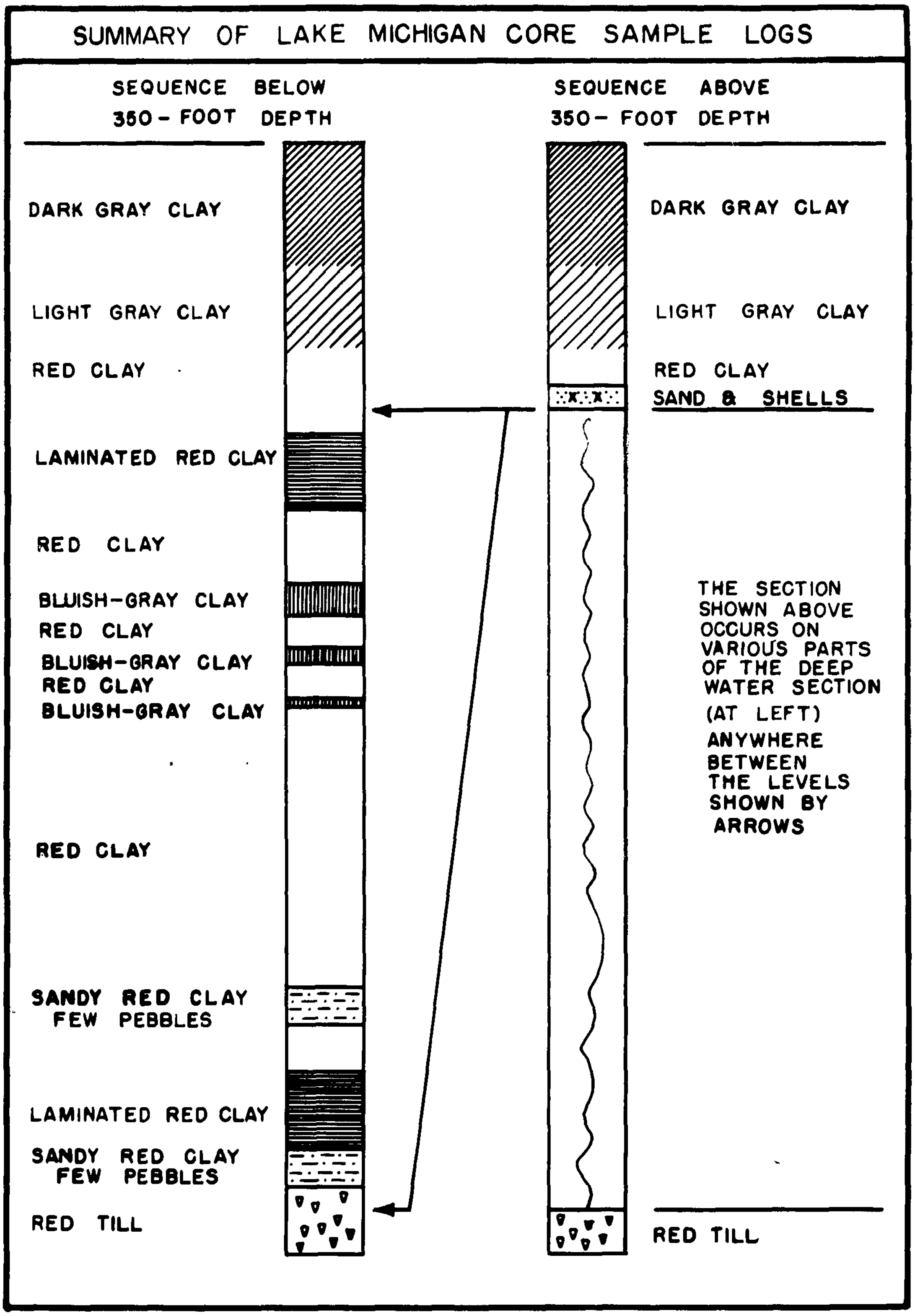

FIG. 8. - Summary of Lake Michigan core sample logs.

The red glacial till is believed to be Valders, or Mankato, in age and to correlate with the red (Valders) till found on shore in the same latitude. Above the red till in core M-1, taken from the deepest point in the lake, there occurs a zone consisting mainly of very fine-grained red clay but including some sand and a very few small pebbles. This zone may simply be an unusually clayey phase of the underlying till, or it may represent deposition in a lake, in which the coarser material was transported by ice-rafting. The next higher zone in core M-1 is a red clay which is distinctly varved in its lower part and indistinctly varved in its upper part. A total of approximately 150 varves was counted. The varved zone grades upward into an unlaminated very fine-grained red clay. This red clay and all of the clays above it contain the same clay minerals and they have approximately the same carbonate content. The color differences apparently are caused by differences in the state of oxidation of iron, since there is no appreciable amount of organic matter present. There is no evidence of shallow water deposition of this material.

Shallow water core samples. - "Shallow water" here means depths less than 350 feet, for convenience in discussing the evidence. All of the major zones of the normal deep water sequence are present in the shallow-water cores, but not in any single core. Many of the individual shallow-water cores have portions of the sequence missing from between upper and lower portions of the standard sequence, and in place of the missing clay members there occurs a thin zone of sand or sand and shells. Logs of sixteen "shallow-water" cores are given in figures 6 and 7, and these serve to establish the relationships of the sedimentary members in depths less than 350 feet. The shallow sequence is illustrated diagrammatically in figure 8.

Evidence of a low water stage in Lake Michigan. - The relationship between the shallow-water sequences and the deep-water sequence of sediments is expressed in figure 9. This is interpreted as a record of deposition of lake clays which was uninterrupted in deep water, but which was interrupted in depths less than the present 350-foot depth. Apparently the normal deep-water sequence was deposited in shallower water also, but there a portion of it was removed by erosion (indicated by truncation of some of the layers), and replaced by a sandy deposit, after which deposition of the normal deep-water sequence was resumed, and continued up to the present time.

The cause of the truncation of some of the clay zones, and deposition of the sand zone on the truncation surface, is believed to be a lowering of the lake surface. Wave action in shallow water and subaerial run off could have caused the truncation of the earlier-deposited clays. Deposition of the sand layer cannot be explained by means of a turbidity flow, in which the sand was buoyed in a clay suspension and transported to deep water, because this mechanism should have carried sand to greater depths as well, and no sand zone is found below the present 350-foot depth. Furthermore, if a turbidity flow mechanism had caused the deposition of one sand zone at various points in the lake, it should have been expected to have produced other sand zones; but only one such zone is found in the lake clay sequence. It is concluded, therefore, on the basis of the physical evidence, that a lowering of the lake level occurred.

Further evidence of a shallow-water condition is found in the shells occurring in the sand zone in some of the cores. These shells were

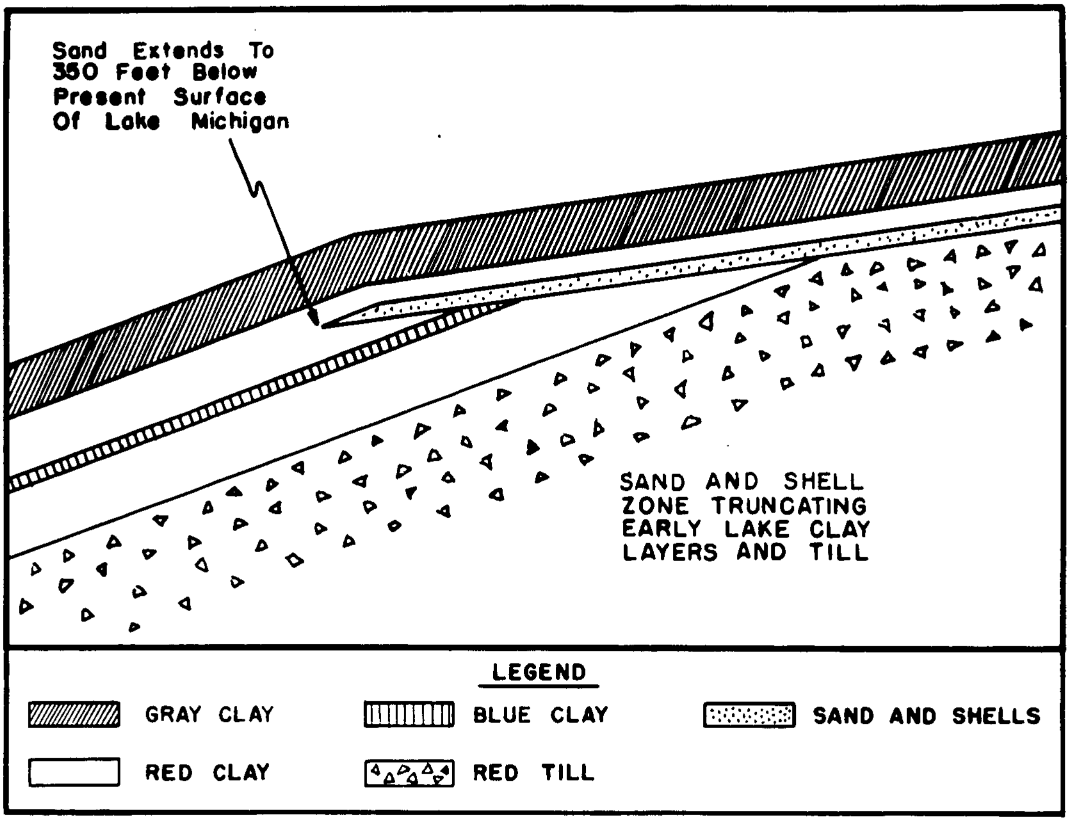

FIG: 9 - Interpretation of Lake Michigan core sample logs. In depths less than 350 feet a sand or sand and shell layer truncates the previously deposited lake clay layers.

submitted to Dr. Max Matteson of the Department of Zoology, University of Illinois, a limnologist and specialist on Recent Mollusca, and were identified by him as Pelecypods and Gastropods which live in extremely shallow water. The majority of the Gastropods were of the genus Valvata, which commonly lives in water 1 to 6 feet deep but occasionally reaches a depth of 30 feet. A few specimens of Amnicola were found. This genus lives in from 1 to 15 feet of water and occasionally lives in swampy areas behind beaches. Pelecypods of the family Sphaeriidae were the most abundant forms. The genus Sphaerium was most abundant and this is reported to live in less than 3 feet of water on any kind of bottom where current action is fairly strong. The genus Musculium was common and it has a depth range of 1 to 10 feet. A few specimens of Pisidium were identified. This form has been reported living in depths up to 100 feet although it is usually restricted to very shallow water. Many of the shells were broken or considerably abraded, indicating that they may have been subjected to wave action. Shells are not found in the normal lake clay zones in the core samples, but are restricted to the zone of the sandy layer and the immediately adjacent sandy clays.

There appears to be abundant evidence for a low-water stage of Lake Michigan, represented by the sand or sand and shell zone occurring within the sequence of lake clays. Since the sand and shell zone extends down to 350 feet below present lake level, and no farther (compare figs. 5 and 6), and considering the extremely shallow habitat of some of the organisms identified, it appears reasonable to assume that lake level was lowered approximately to the 350 foot depth or to an elevation of 230 feet A.T.

Names of the low stage lakes. - The low-water stage in Lake Michigan is named Lake Chippewa. The name "Chippewa" is chosen in order to have an Indian name to associate with "Algonquin," which has been used to designate an earlier, higher lake stage, and because the Chippewa Indians lived in this region and were related to the Algonquins in many respects of their culture. The water in the Michigan basin could not have been drained down to the Chippewa level (230 feet A.T.) unless the water in the Huron basin were also at least that low, and thus the low stage in the Huron basin which was postulated by Stanley (1936, 1937) must actually have existed. The name Lake Stanley is selected for the Huron basin low stage, in recognition of the work of George M. Stanley.

Channel connecting Lakes Chippewa and Stanley. - A submerged valley through the Straits of Mackinac, connecting Lakes Michigan and Huron, has been described in detail by Stanley (1938). The head portion of this valley in Lake Michigan has a present depth of 150 feet, and in general the valley deepens in its 70-mile course eastward, through the Straits, into Lake Huron where channel depths in excess of 200 feet occur. Maximum observed depths along the course of the channel are less than 150 feet in a few places. It is possible that the deepest points on the various cross sections were missed during sounding operations, and it is also possible that sediment has been deposited in the channel in recent time, being carried in by the strong currents which are known to exist in the vicinity of reefs and islands near the channel. It appears reasonable, therefore, to consider the channel as having a controlling depth of 150 feet. Uplift of slightly more than 200 feet has occurred at Mackinac Island, where the highest Algonquin beach is now 232 feet above lake level. By adding 200 feet of uplift to a present controlling depth of 150 feet, it is calculated that the Michigan basin waters would have been lowered

350 below present lake level by drainage through this channel into Lake Stanley. This value coincides with the amount of lowering which was indicated by the evidence of the core samples.

The name "Mackinac River" is given to the discharge of Lake Chippewa through the channel leading to Lake Stanley (see fig. 10).

<u>Extent and configuration of Lake Chippewa</u>. - A reconstruction of Lake Chippewa is shown in figure 10. This was made with the aid of a topographic map of the lake bottom which was prepared by the writer from published charts and from unpublished U. S. Lake Survey data. In the unwarped part of the basin the Lake Chippewa shore was drawn on the present 350 foot depth contour. In the northern part of the basin allowance was made for the warping which has occurred since the Chippewa stage. In following the 350-foot depth contour southward from the central portion of the lake the contour was found to close off the southern third of the lake at a latitude slightly north of Grand Haven, Michigan. Farther south is a deep basin with a maximum present depth of 564 feet. The deepest point on the divide between the southern and the northern basins is at a depth of 336 feet; therefore, there must have been a separate lake in the southern basin at an elevation of 336 feet below present lake level (244 feet A.T.) during the low-water stage in the Michigan basin. This southern lake is named "Southern Lake Chippewa."

A fairly definite channel connecting Southern Lake Chippewa with the main Lake Chippewa can be found both on a detailed topographic map of the divide area (prepared by the writer from unpublished soundings made by the U. S. Lake Survey) and on fathogram cross sections of the area. It is proposed that the discharge through this channel during the low level

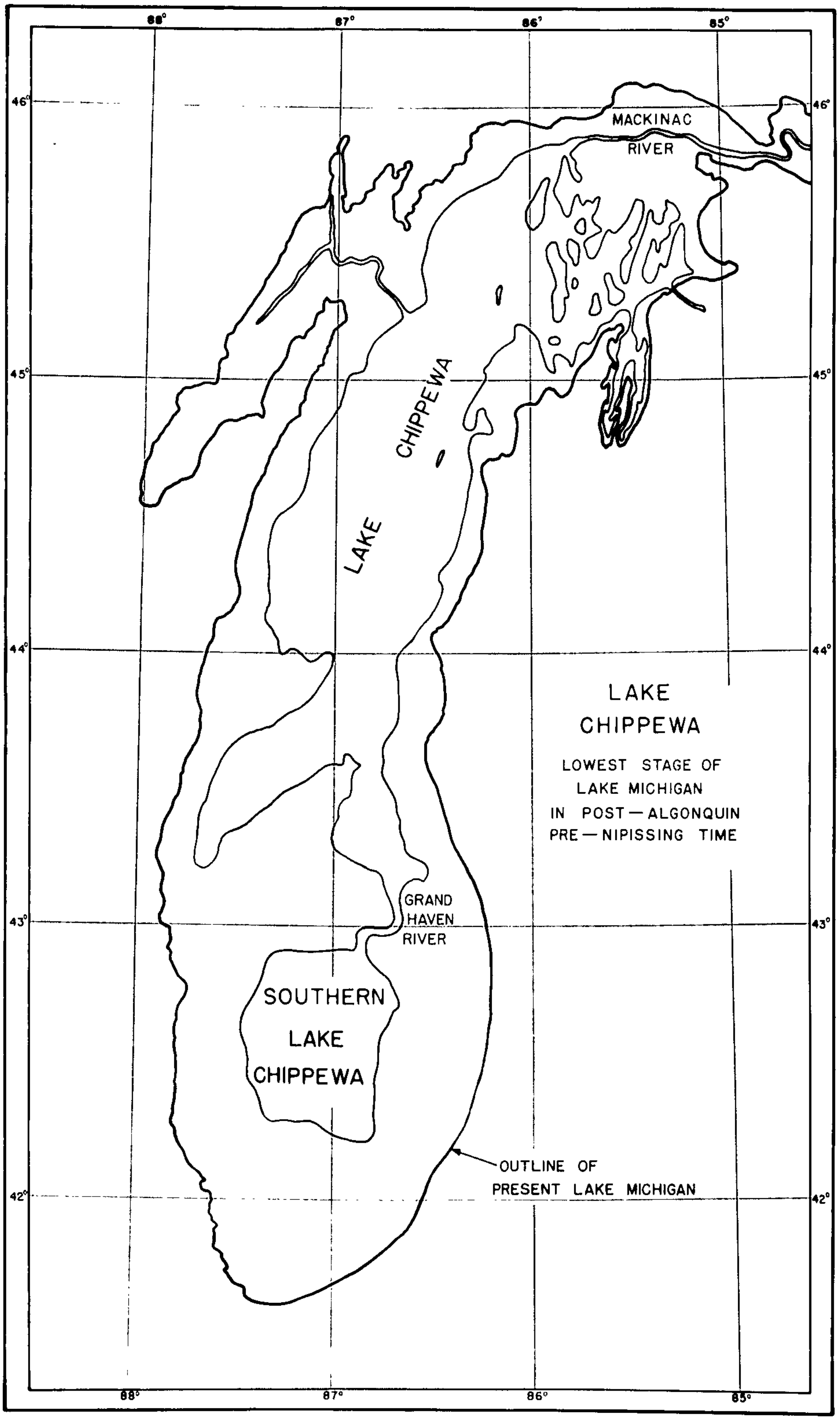

FIG. 10 -- Reconstruction of Lake Chippewa in the Lake Michigan basin.

stage be named the Grand Haven River, after the city on the adjacent eastern shore of Lake Michigan.

<u>The outlet of Lake Stanley</u>. - Lake Stanley discharged through the North Bay outlet, northeast of Georgian Bay, and down the Mattawa and Ottawa rivers to the St. Lawrence Valley. This outlet was made available when the glacial ice front receded north of the channel, at a time before much of the post-glacial upwarping had taken place.

The amount of upwarp of the outlet which has occurred since the Chippewa-Stanley time of extreme low water is at least 420 feet. This figure was obtained as follows: The elevation of Lake Chippewa was 230 feet A.T., and the Mackinac River channel leading from Lake Chippewa to Lake Stanley can be traced on a Lake Huron bottom contour chart to a depth 50 feet lower than its head; the elevation of Lake Stanley was, therefore, at least as low as 180 feet A.T.; because the present elevation of the Lake Stanley outlet at North Bay is about 600 feet, it must have been raised from 180 to 600 feet A.T., or a vertical distance of 420 feet. If the Stanley stage were lower than 180 feet, the amount of uplift has been greater.

<u>Close of the Chippewa-Stanley stages</u>. - The extreme low-water stages were brought to a close by upwarp of the outlet area. The North Bay outlet continued as the only dischargeway for the lake in the Huron basin until the water level in the basin was raised to the elevation of the old southern outlet channels. During this period of rise the lakes in the Michigan and Huron basins may be considered as transitional stages between Chippewa-Stanley and the Nipissing stage.

The Nipissing Great Lakes

The concept of the Nipissing Great Lakes presented by Leverett and Taylor (1915, pp. 447-462) must be revised in the light of the work of Stanley (1936, 1937) and of the present project. A map of the Nipissing Great Lakes is given in figure 26.

<u>Definition of the Nipissing stage</u>. - The original Nipissing stage beach is a feature near the shore of modern Lake Nippissing in the vicinity of the North Bay outlet, in Ontario northeast of Georgian Bay. This beach has been correlated with a strong strand line which occurs in the upper Huron basin, the upper Michigan basin, and the southeastern part of the Superior basin. It is this more extensive beach which has become the "type" Nipissing beach. Taylor (Leverett and Taylor, 1915, p. 449) wrote: "The name 'Nipissing beach' has from the first been applied to the shore line now known to have been formed during the two-outlet stage of the lakes, when the discharge was deserting North Bay and returning to Port Huron...." The present writer accepts this part of Taylor's concept of the Nipissing stage, because it is based on field evidence. He adds a possible third point of discharge (the Chicago outlet) however, for reasons to be stated later.

<u>Description of the Nipissing beach</u>. - The beach occurring in the upper Huron and Michigan basins and in the southeastern Superior basin which is accepted by all students of Great Lakes history as Nipissing has unusually distinctive characteristics. It is not only one of the most strongly developed beaches of the region, but it is a remarkably fresh, undissected feature built upon dissected topography. This aspect of the

beach was not adequately described by Leverett and Taylor, but was recognized by the writer. Above the Nipissing beach the land generally is creased by gullys or small valleys which terminate at the Nipissing beach, and the spurs of the divides between these valleys are truncated at the upper margin of the beach. These relationships are interpreted by the writer to mean that a low-water stage occurred before the Nipissing beach was built, and that during the low-water stage the gullys and valleys were cut. When the lake surface rose to the Nipissing level, the spurs of the divides were truncated by wave erosion, beach deposits were laid in front of the spurs and across the valley mouths, and the floors of the gullys and smaller valleys were graded to the level of the beach. The Nipissing beach crosses the mouths of larger valleys as a barrier, enclosing lower ground, swamps or lakes.

The next generally recognizable beach below the Nipissing is the Algoma beach, which is represented by a bench or step in the otherwise smoothly sloping surface from the Nipissing down to present lake level.

Initiation of the Nipissing stage. - Taylor had assumed that the "lower Algonquin" beaches, or all of the beaches lying between the "highest Algonquin" and the Nipissing, were formed during a period of upwarp while the lakes drained through the Port Huron and Chicago outlets. He assumed that the Nipissing stage came into existence when retreating ice uncovered the North Bay outlet, thus draining the lakes down below the (unwarped) Algonquin level. Because the greater part of the upwarp recorded by the highest Algonquin beach had already occurred, according to Taylor's hypothesis, his original or earliest Nipissing stage with a single outlet at North Bay was not an extremely low stage (it was placed at "530±" feet A.T. in the table on p. 469, Leverett and Taylor, 1915). This hypothetical earliest Nipissing beach was not based on field evidence. Taylor wrote: "Knowledge concerning the beginning of the Nipissing Great Lakes and the transition to them from Lake Algonquin is rather meager, but the condition of the lakes themselves and the transition from them to the present lakes is clearly recorded in the beaches" (Leverett and Taylor, 1915, p. 447). Stanley (1936, 1937) and the writer have contributed evidence concerning the transition from the Algonquin to the Nipissing stage, and Taylor's concept of a hypothetical earliest Nipissing stage may be abandoned.

In the revised history, a post-Algonquin extremely low stage occurred (Lakes Chippewa and Stanley), far below the level of Taylor's hypothetical earliest Nipissing, and the lakes then were raised continuously until they spilled through the old southern outlets. The first (and only) "Nipissing" stage came into existence at the level determined by the southern outlets. This lake stage is recorded by the Nipissing beaches described above.

<u>Duration of the Nipissing stage</u>. - The strength of development of the beaches indicates that the lake stood at the Nipissing level for a considerable period of time. This static stage is explained as follows. When discharge through the southern outlets was well established, the lake surface could rise no higher even though uplift of the northern outlet continued. Downcutting of the southern outlets by the discharging streams presumably would not have begun while any significant part of the discharge of the three upper lakes still spilled through the North Bay outlet. The southern outlets had been adjusted to carry the discharge of Lake Algonquin which occupied the Huron and Michigan basins, and a greater volume of discharge presumably would be required to cut down the outlets

in Nipissing time. It was only after the North Bay outlet was abandoned in late Nipissing time that the entire discharge of the Huron, Michigan and Superior basins flowed through the southern outlets.

Elevation of the Nipissing stage. - The elevation of the Nipissing stage is yet to be determined. The definitely identified parts of the Nipissing beach have been warped upward since they were formed. They occur at the following elevations:

Elevation, in feet A.T.	Locality
650	Sault Ste. Marie, Ontario
630	Mackinac Island, Michigan
615	Harbor Springs, Michigan
606	Elk Rapids, Michigan

There has been some controversy over the correlation of this beach with shore features in the southern parts of the Huron and Michigan basins. Taylor (Leverett and Taylor, 1915, p. 468) wrote: "Unfortunately, when Gilbert finished his investigations (1896) the position and attitude of the Nipissing plane in the southern parts of the basins of Lakes Huron and Michigan had not been correctly determined. It was then supposed that both the Algonquin and Nipissing beaches passed under the present lake level southward, the Nipissing being about 20 feet beneath it at Port Huron and about 100 feet beneath it at Chicago. These, however, were estimates based chiefly on the planes of the beaches produced from the north and partly on erroneous determinations of the places where the planes cut the lake surface. The responsibility for these errors is shared by Spencer and the writer." Taylor then stated that he has found "that, instead of passing under the lake surface southward both beaches become horizontal, the Algonquin at about 25 feet above the present lake level and the Nipissing at about 15 feet." Taylor had no additional facts of any significance when the last quoted statement was made.

It is impossible to trace the known Nipissing beach from the northern areas down to a junction with any southern beaches, for the reason given by Taylor himself (p. 450): "On certain shores the Nipissing beach has been largely and in places almost wholly cut away at present lake level. This is notably the case along the east side of the "thumb" north of Port Huron, on both sides of Lake Michigan, and on the east side of Lake Huron." A careful reading of the Leverett and Taylor monograph reveals that all of the beaches above the present lakes are absent in the critical areas. Both the Algonquin and the Nipissing beaches have been traced down from the North nearly to the unwarped Algonquin level (605 feet), but correlation with beaches to the south are based on conjecture.

In discussing the warping of the beaches, Taylor wrote: "The differential elevation which affected the Nipissing beach appears to have hinged on the same line as that which affected the highest Algonquin beach. This relation seems clearly established in the basin of Lake Michigan, but owing to the difficulty of determining the Nipissing beach, it remains somewhat uncertain in the basin of Lake Huron" (p. 449). In regard to the beaches in the basin of Lake Michigan Goldthwait (1907), in "The Abandoned Shorelines of Eastern Wisconsin," wrote: "In the plotted profile (Plate XXXVII) no attempt is made to carry the Algonquin planes down to their points of coincidence with each other or with the Nipissing plane. There are not enough data in Eastern Wisconsin to warrent so complete a reconstruction. But on the basis of what has been found elsewhere regarding the history of Lake Algonquin and Nipissing....a hypothetical profile may be worked out...." (p. 111). And on page 109 Goldthwait wrote: "Taylor's more recent work in Michigan has suggested that the Nipissing beach extends farther south above the present lake. His acceptance of the strong 20-foot shore-line of Door County as the Nipissing shore-line, in a letter of Sept. 11, 1905, leaves little doubt as to its identity." Taylor's letter to Goldthwait,[1] (actually dated Sept. 9, 1905) read, in part: "I am quite sure that your two sets of beaches, the upper, tilted ones, and the lower nearly horizontal ones, are the Algonquin and Nipissing, respectively. Instead of dipping under the present lake near Gladstone, as I concluded in my early paper (mainly theoretically) the Nipissing probably comes to horizontality somewhere near the 'Door.' This is suggested by my later work on the east shore of Lake Michigan and on Lake Huron....In the south part of Lake Huron the Algonquin becomes horizontal at about 23 ft. or sometimes 25 ft. above the lake, and the Nipissing the same at about 9 feet....The nodal points mentioned by Mr. Leverett are partly theoretical for the west side of the Michigan basin, or at least not fully or exactly established by observation."

In summary of the material quoted above, it is obvious that Taylor had no basis in fact for his insistence that the Nipissing beach could be projected southward to join with a horizontal beach at an elevation of 590 or 596 feet. The correlative of the Nipissing beach in the south is unknown.

The writer proposes that the Nipissing beach may be represented in the south by the Toleston and Algonquin level beaches, at the elevation of

1. This letter has been preserved, and it was loaned to the writer by Professor R. P. Goldthwait of Ohio State University.

605 feet. This is suggested in view of the probability that the draining of Lake Algonquin by diversion of discharge to a new, lower, outlet left the Port Huron and Chicago outlets at their Algonquin levels. If this actually were the case, a later rise of the lakes to the Nipissing stage would involve a re-use of the old Algonquin level outlets, and the Nipissing level would be the same as the Algonquin level. This proposal is supported by a comparison of the strengths of development of the various beaches involved in the controversy. The accepted Nipissing beach in the North is one of the strongest beaches in the Great Lakes Region. In the unwarped southern area there is no beach between the Toleston-Algonquin level, 605 feet, and the present lake level, 581 feet, which compares in strength with the accepted Nipissing to the North. The Toleston-Algonquin level beach in the south does compare favorably. This proposal also is supported by radiocarbon dates obtained for woody material taken from the beach deposits.

Radiocarbon dates of the Nipissing beach. - The Nipissing beach along the southern shore of Lake Superior presumably is correctly identified, because it is north of the area in which correlation difficulties have been so acute. A sample of peat collected from the Nipissing beach at Sand Island, Bayfield County, Wisconsin, has been dated as 3656 ± 640 years old (Arnold and Libby, 1951).

A sample of wood from the "Toleston level" beach at Dalton, Illinois, has been dated as 3469 ± 230 years old (Arnold and Libby, 1951). If the reasonably well-established Nipissing beach of southern Lake Superior is 3656 years old, the 3469-year date is unacceptable for the Toleston stage. If, however, the Nipissing stage existed in the southern part of the

Michigan basin at the same elevation as the Algonquin and Toleston, the "Toleston level" beach date could apply to the Nipissing stage.

A sample of charcoal from the "Nipissing" level--596 feet--at the Burley site near Port Franks, Ontario, on the southeastern shore of Lake Huron has been dated as 2619 $\pm$ 220 years old (Libby, 1952). If the Nipissing stage existed in the southern part of the Huron basin at the 605-foot, rather than the 596-foot level, this date would not apply to the Nipissing stage. It could more appropriately be assigned to the later Algoma stage, which will be described in the next section of the report. The geologic relations of the Burley site dated charcoal horizon must be accounted for before the 2600-year date can be accepted as post-Nipissing. This will be discussed under the Algoma stage.

Close of the Nipissing stage. - The Nipissing stage, after enduring long enough to form one of the strongest beaches in the region, apparently was brought to a close by downcutting of the Port Huron outlet. The lake level was lowered from the Nipissing beach to the Algoma beach relatively rapidly, according to the field evidence in the area of the accepted Nipissing beach; there are no well-marked intermediate stages in this interval. The occurrence of a period of rapid downcutting after a long static period requires an explanation, and one has already been suggested in the discussion of the duration of the Nipissing stage: that during the static-level Nipissing stage a part of the discharge flowed through the North Bay outlet, and that when the North Bay outlet was raised above the Nipissing level, causing the entire discharge to pass through the southern outlets, downcutting began.

The Algoma Stage

In the northern parts of the Michigan and Huron basins and in the vicinity of Sault Ste. Marie, where the identity of the Nipissing beach is unquestioned, the next well-developed beach below the Nipissing is the Algoma. This beach was named from its occurrence at Algoma Mills, Ontario (on the north channel of Lake Huron), where it lies 35 feet below the Nipissing and 50 feet above present lake level (Leverett and Taylor, 1915, p. 464). In the area between Grand Traverse Bay and Charlevoix, on the lower peninsula of Michigan (where the writer has observed the beach features in greatest detail), the Algoma is the first recognizable beach below the Nipissing and it is the strongest of the Nipissing to present sequence. Between the Algoma and the present level there are two or three weakly developed beaches which are too faint to attract much attention. The Algoma beach is not as strong a feature as the Nipissing beach.

Because Taylor had correlated the northern Nipissing beach with the weaker beach in the southern parts of the Michigan and Huron basins at elevation 596 feet, he assumed that the northern Algoma beach must correlate with one of the still weaker beaches below that level in the south. In the present revision of the lake history the northern Nipissing beach is correlated with the strong beach at the 605-foot level in the south, and therefore the Algoma may be correlated with the weaker beach at 596 feet in the south

If the Algoma stage stood at 596 feet, its discharge was largely through the Port Huron outlet. A small part of the discharge apparently would have gone through the Chicago outlet, because the sill at that outlet is about 8 feet above present lake level (Leverett and Taylor, 1915,

p. 449) or approximately at 590 feet.

The Algoma beach undoubtedly records a static level of the lake, but the reason for the static level is unknown. Presumably there was a pause in the downcutting of the Port Huron outlet. This pause and the subsequent downcutting may possibly be correlated with an evidently very recent shift of the Detroit River channel from a boulder-paved and bed rock-floored channel to a deeper channel in drift by lateral migration (Leverett and Taylor, 1915, pp. 494-495).

A radiocarbon date of 2619 ± 220 years has been obtained for a sample of charcoal taken from an elevation of 596 feet at the Burley site on the southeastern shore of Lake Huron (as mentioned above in the discussion of the Nipissing beach). This was reported as a Nipissing-level site by Dreimanis (1952), who accepted Taylor's correlation of the Nipissing. If it is assumed, however, that the Nipissing level was at 605 feet, the charcoal then apparently came from the Algoma, or from slightly below the Algoma level. The charcoal was associated with artifacts and other evidences of human occupation in a 1- to 2- foot thick layer of dark sand. This layer was overlain by 1 to 3 feet of stratified sand containing several streaks rich in plant remains and containing shells of a fresh-water clam and a land snail. Above this were a total of about 8 feet of sand, apparently of wind-blown origin but containing two additional occupational sites.

It appears to the writer, who has not visited the site, that this sequence of deposits may represent an alluviation of the site first by river flood plain or delta deposition, then by wind deposition, above a lake level which was no higher than the base of the sequence. No evidence has been presented to indicate that lake level had risen over the first occupational site, from which the dated specimen was obtained.

Transition from the Algoma stage to the present

Between Algoma time and the present, lake level in the Huron and Michigan basins fell with only minor pauses leaving weakly-developed strand lines. The lowering apparently was the result of downcutting of the Port Huron outlet channel.

When the water level in the Huron basin fell below the sill in the St. Marys River valley, Lake Superior was finally separated as a lake with a higher level.

Upwarp of the land in the north has raised the Nipissing and Algoma beaches, and apparently it continues at the present time according to the results of lake level studies (Moore, 1948).

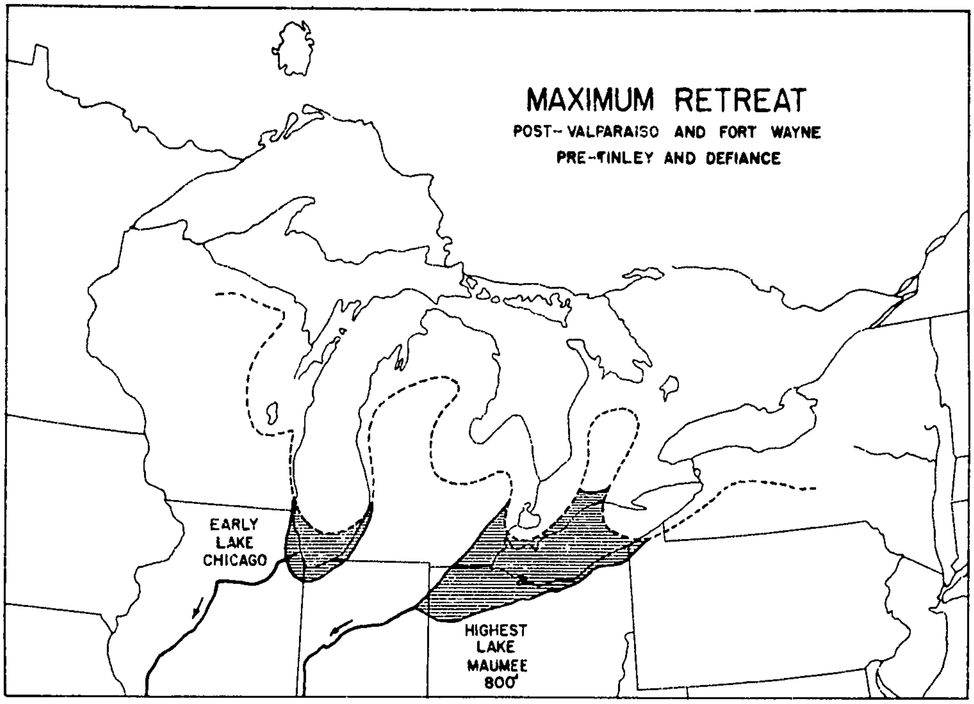

FIG. 11. - Lake stage map no. 1: Early Lake Chicago and Highest Lake Maumee.

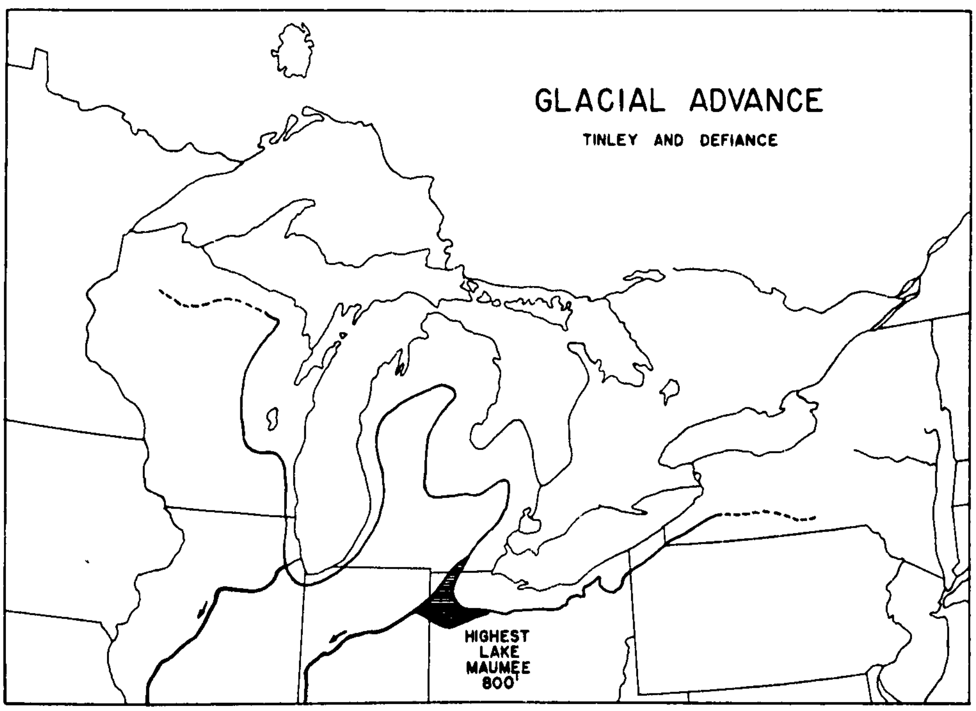

FIG. 12. - Lake stage map no. 2: Highest Lake Maumee.

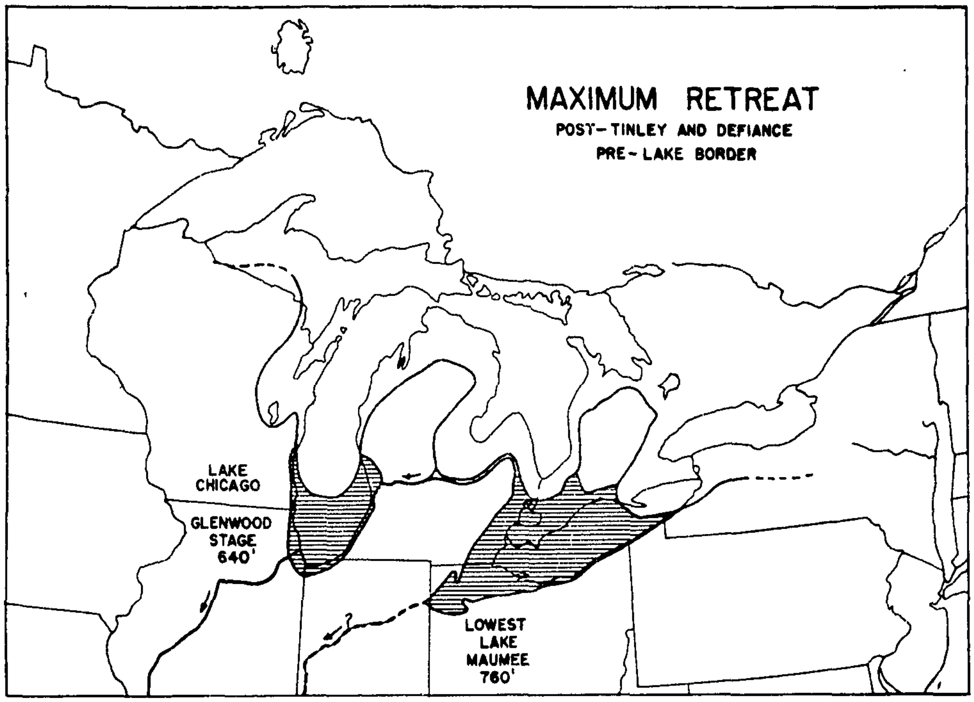

FIG. 13. - Lake stage map no. 3: Lake Chicago Glenwood stage and Lowest Lake Maumee.

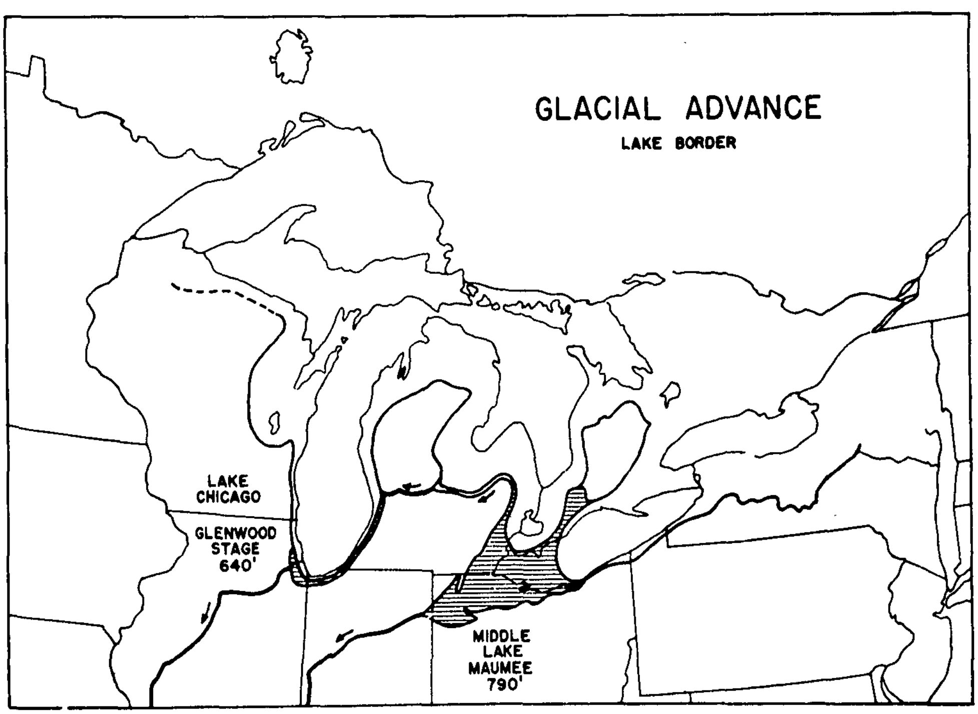

FIG. 14. - Lake stage map no. 4: Lake Chicago Glenwood stage and Middle Lake Maumee.

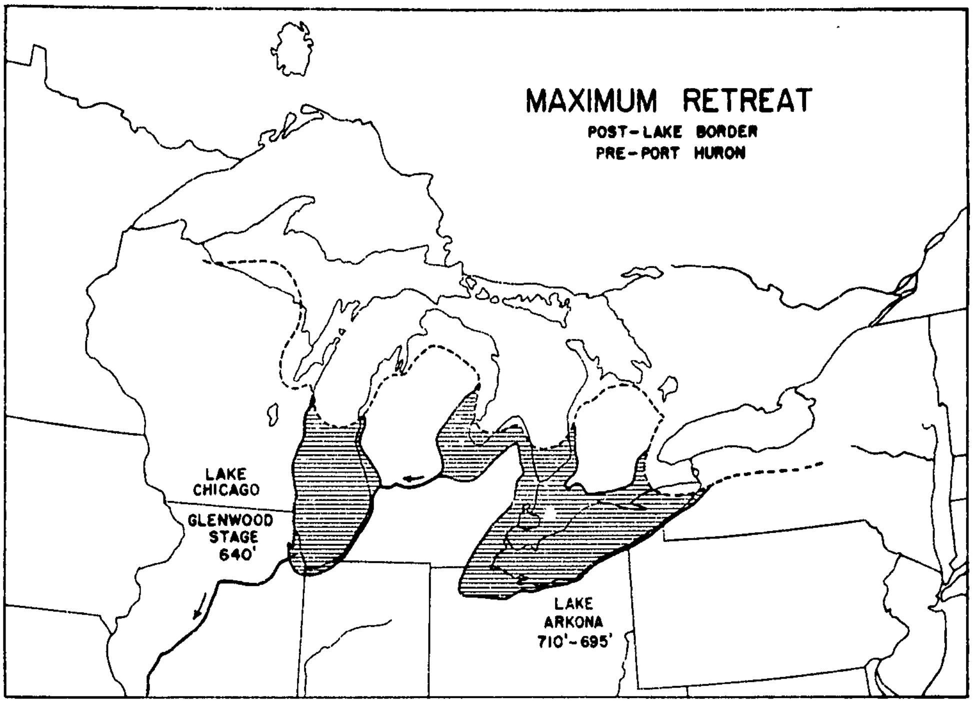

FIG. 15. - Lake stage map no. 5: Lake Chicago Glenwood stage and Lake Arkona.

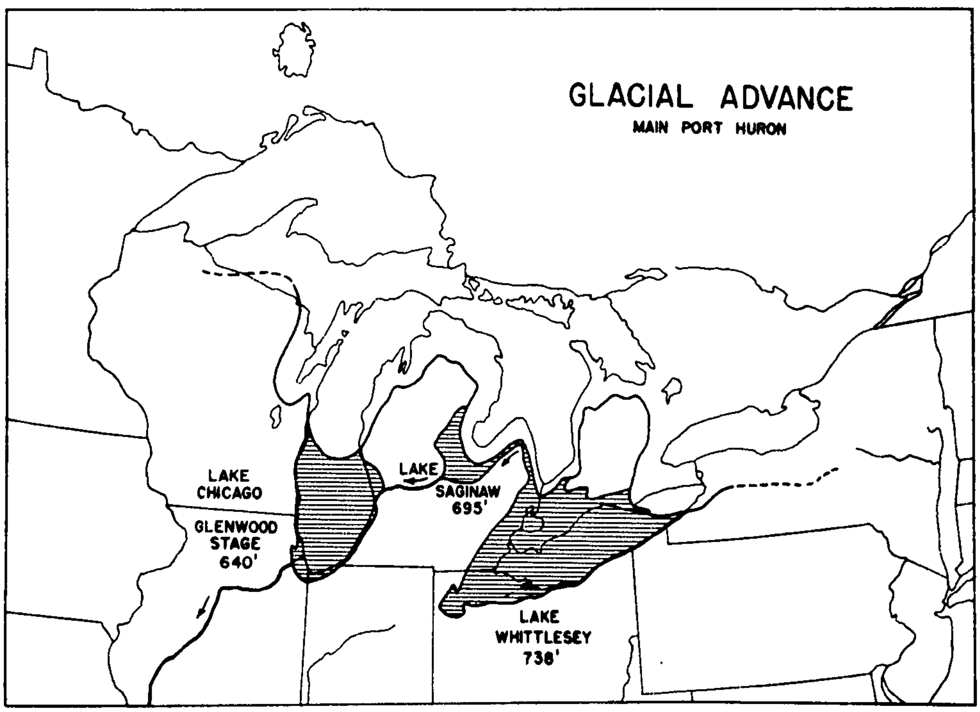

FIG. 16. - Lake stage map no. 6: Lake Chicago Glenwood stage and Lake Whittlesey.

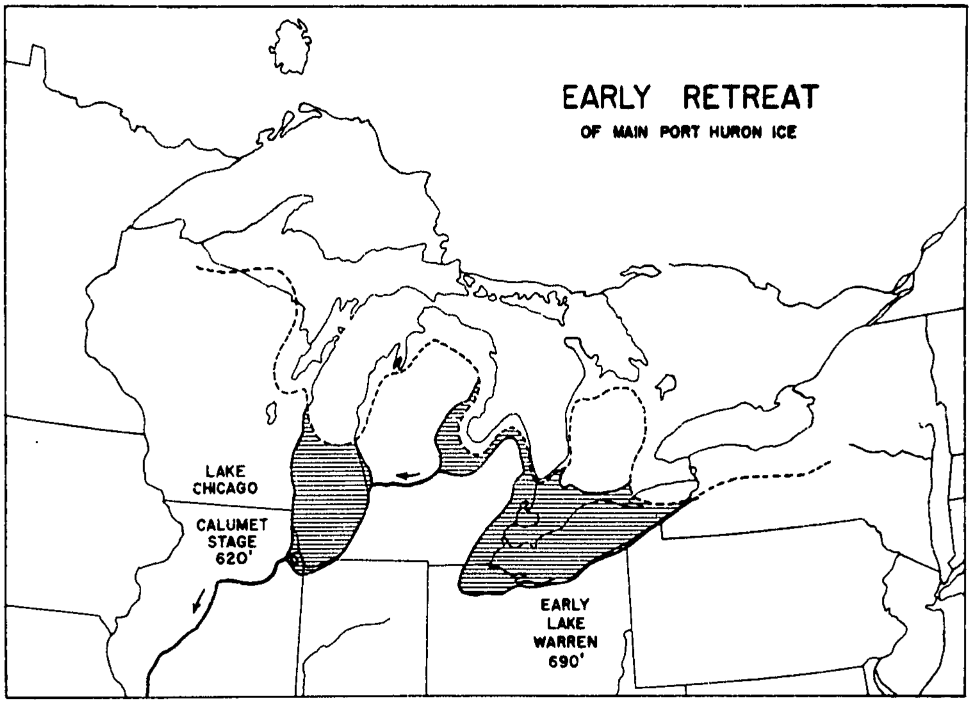

FIG. 17. - Lake stage map no. 7: Lake Chicago Calumet stage no. 1 and Early Lake Warren.

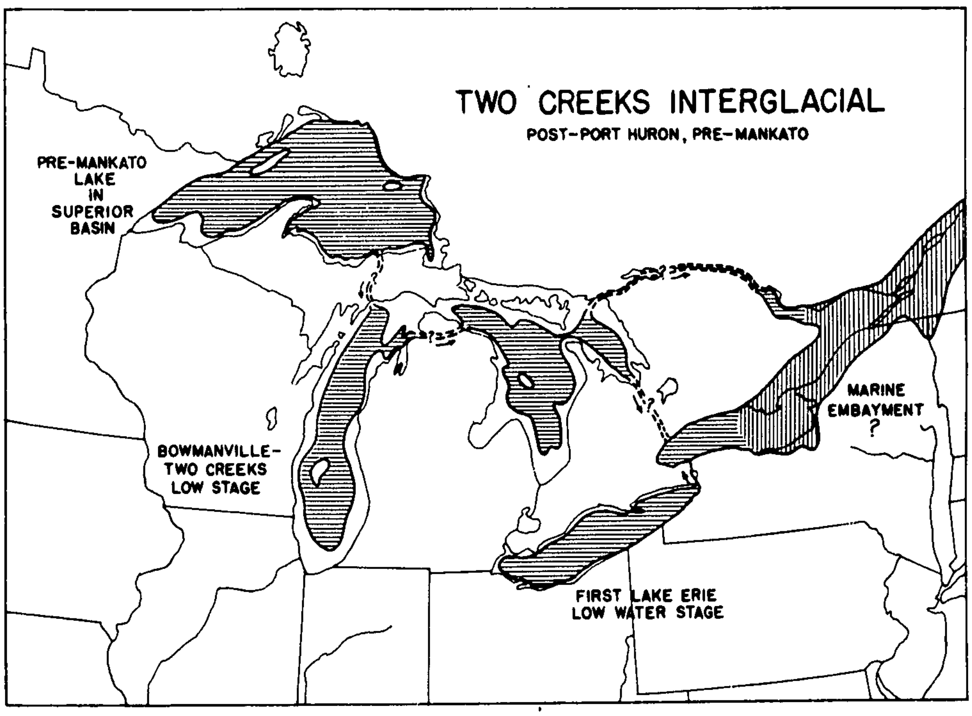

FIG. 18. - Lake stage map no. 8: Two Creeks interval low stage lakes.

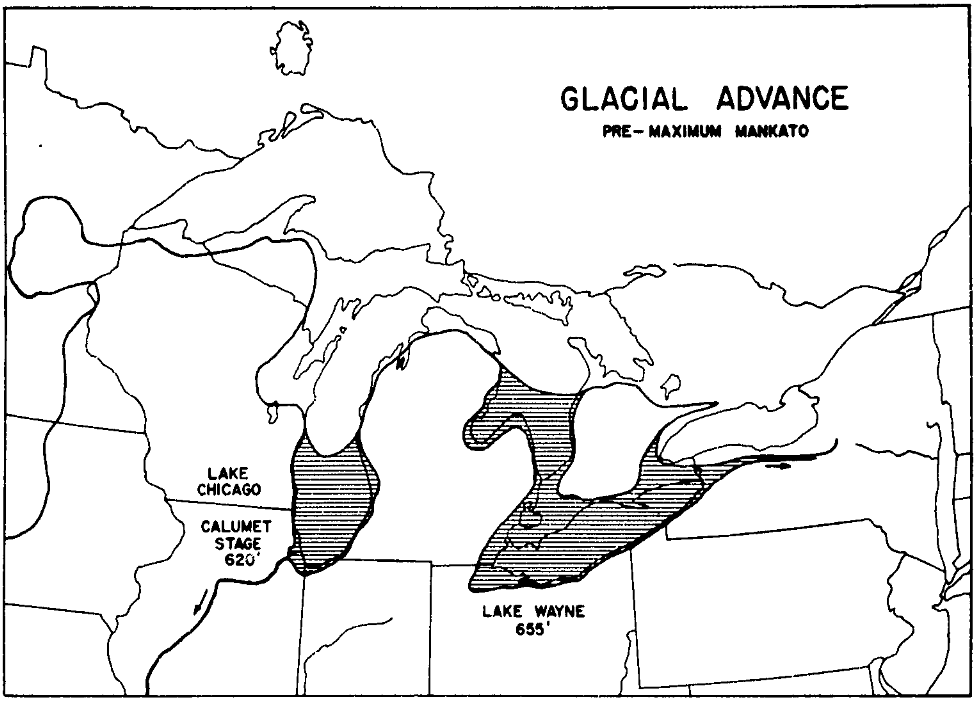

FIG. 19. - Lake stage map no. 9: Lake Chicago Calumet stage no. 2 and Lake Wayne.

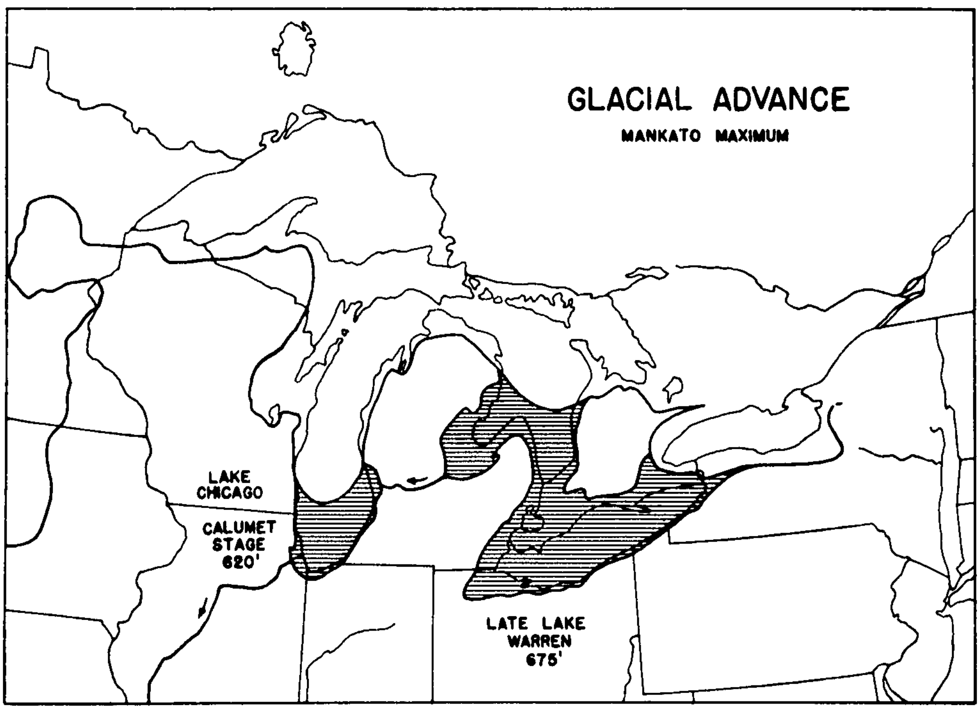

FIG. 20. - Lake stage map no. 10: Lake Chicago Calumet stage no. 2 and Late Lake Warren.

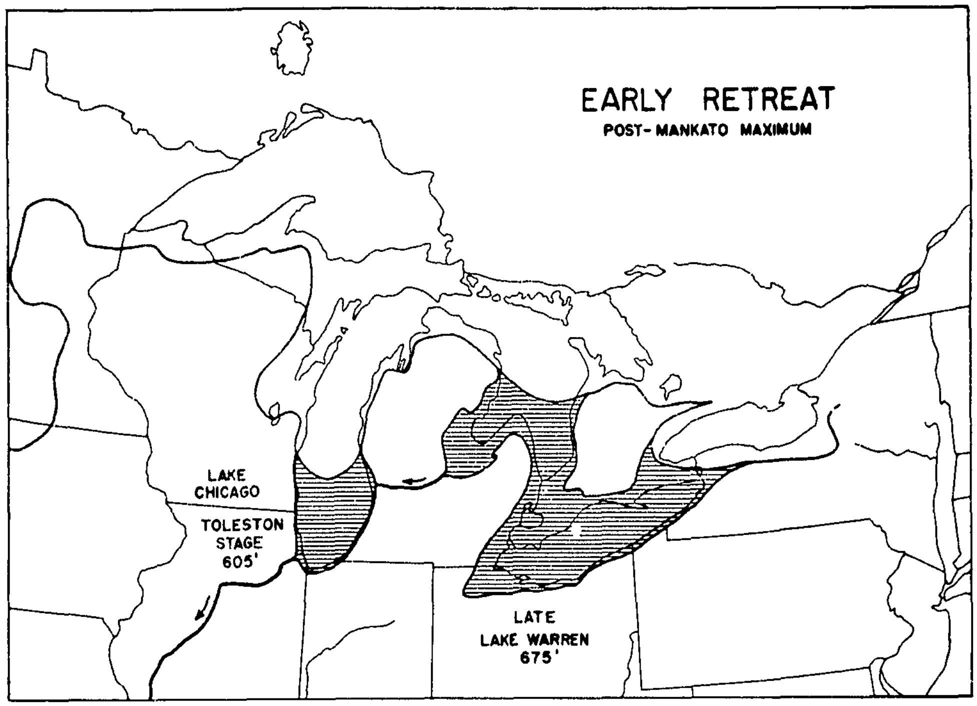

FIG. 21. - Lake stage map no. 11: Lake Chicago Toleston stage and Late Lake Warren.

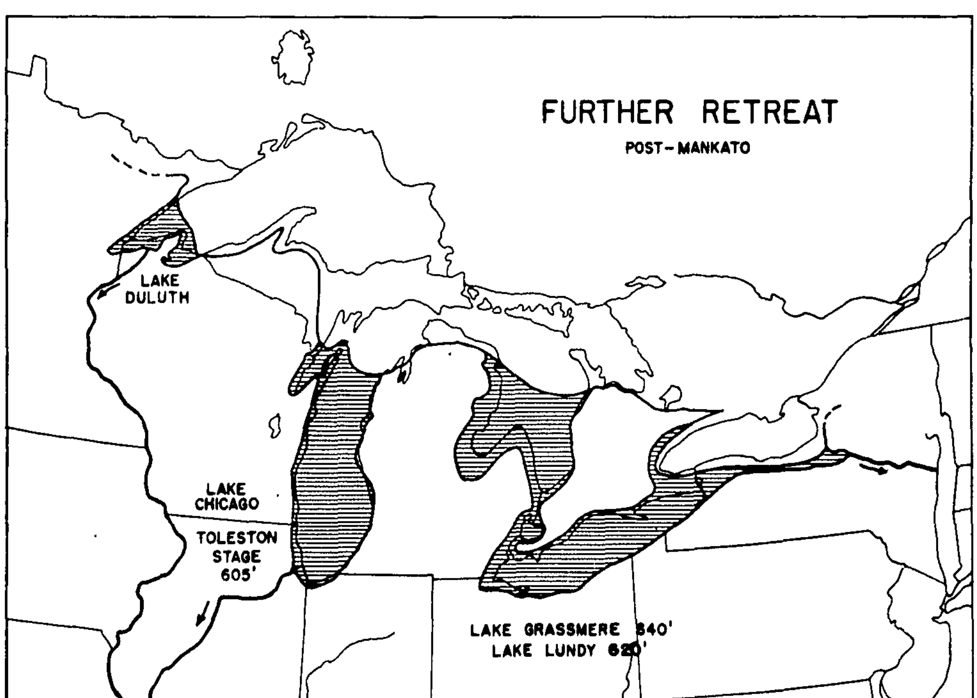

FIG. 22. - Lake stage map no. 12: Lake Chicago Toleston stage, Lakes Grassmere and Lundy, and Lake Duluth.

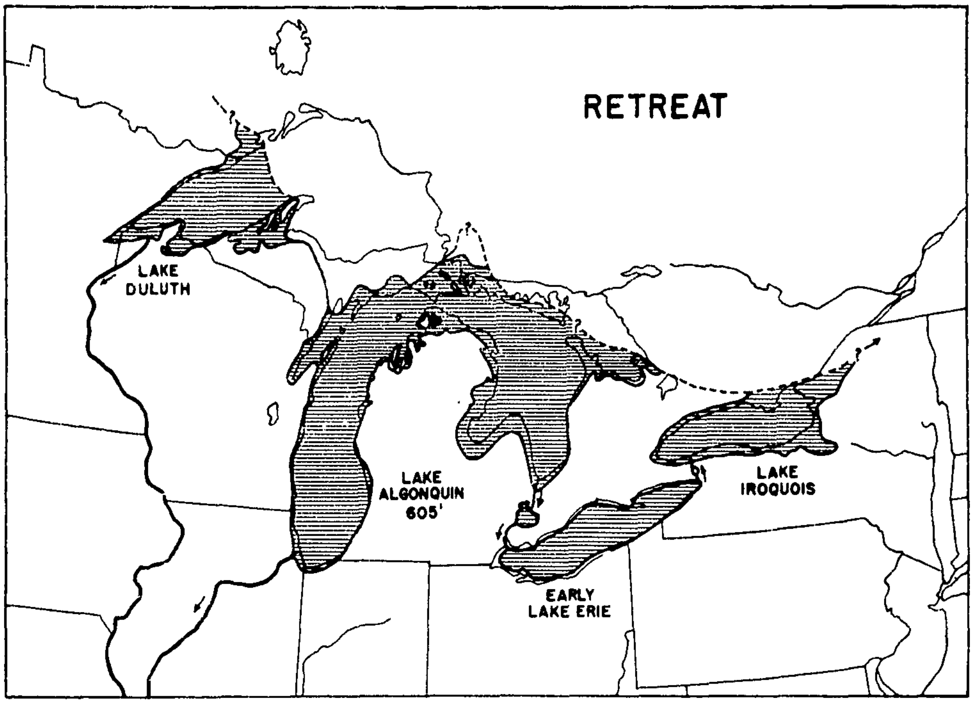

FIG. 23. - Lake stage map no. 13: Lake Algonquin, Lake Duluth, Early Lake Erie, and Lake Iroquois.

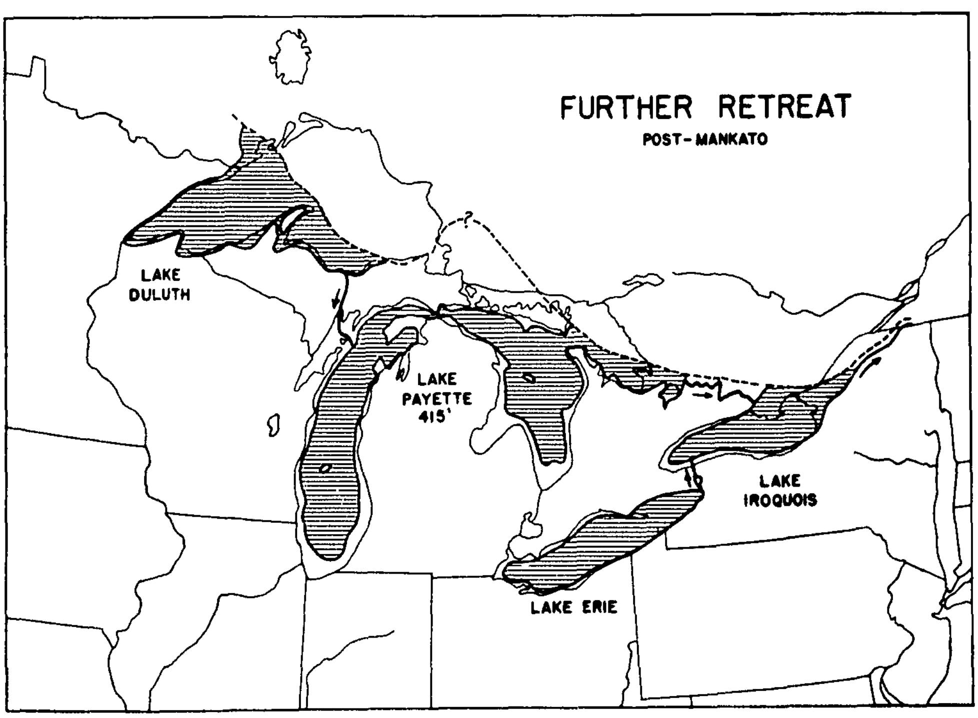

FIG. 24. - Lake stage map no. 14: Lake Payette, Lake Duluth, Lake Erie and Lake Iroquois.

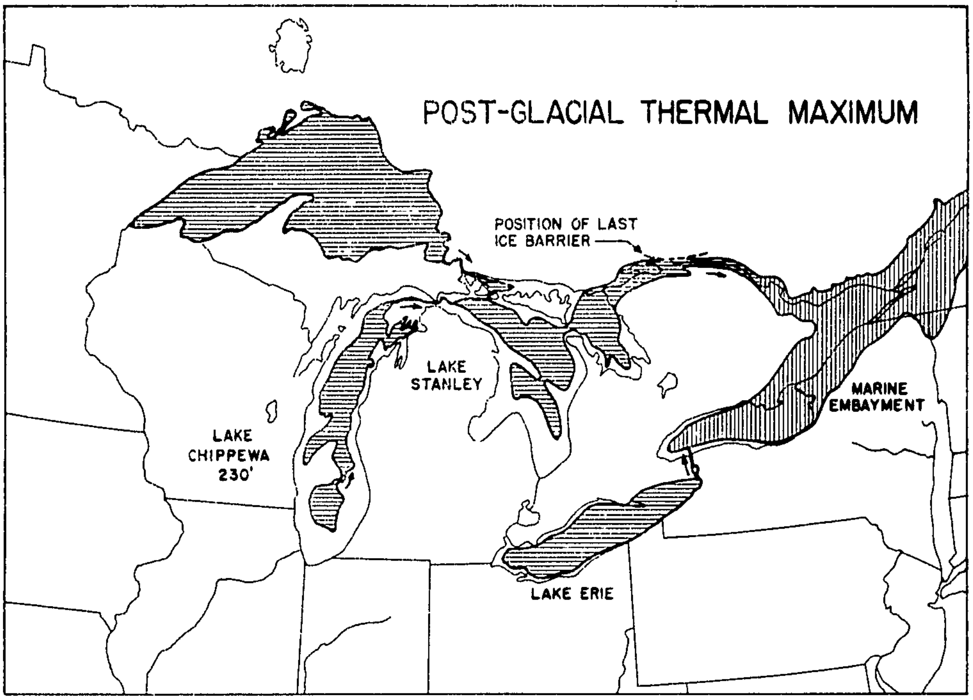

FIG. 25. - Lake stage map no. 15: Lake Chippewa, Lake Stanley, Early Lake Superior, Lake Erie, Ontario marine embayment.

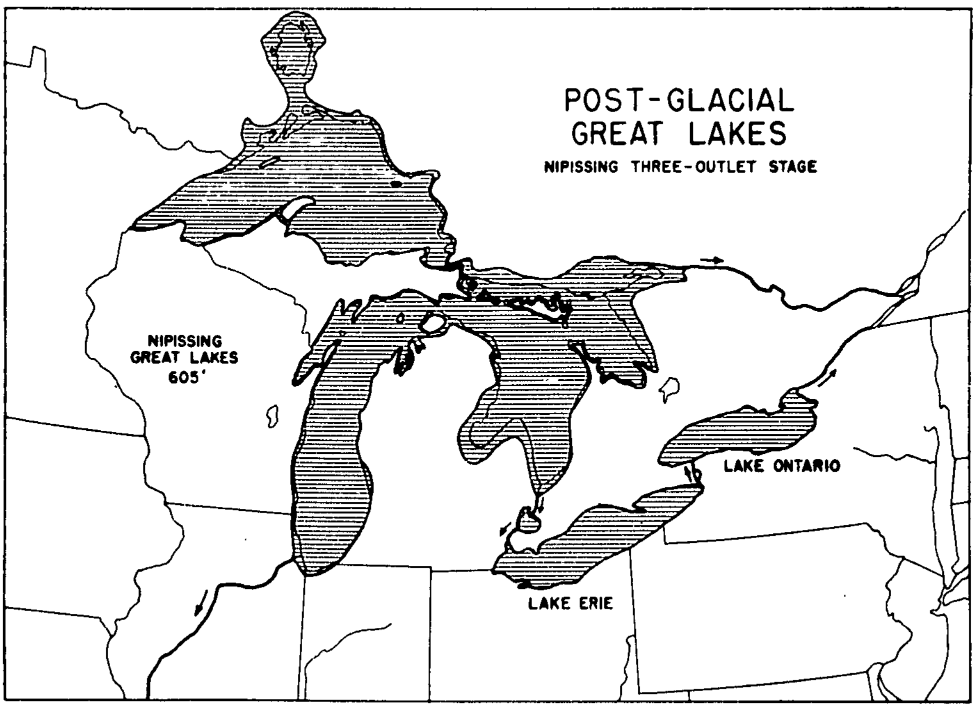

FIG. 26. - Lake stage map no. 16: Nipissing Great Lakes.

FATHOGRAM INDICATIONS OF BOTTOM MATERIALS IN LAKE MICHIGAN

A detailed report on this subject has been published in the Journal of Sedimentary Petrology, vol. 22, no. 3, pp. 162-172, figs. 1-8, September, 1952. A reprint of this paper is enclosed in the present report as Supplement No. 1. An abstract of this paper follows.

Abstract

Fathograms recorded by a commercial sonic sounding apparatus used in a study of the bottom sediments of Lake Michigan show characteristic traces for sand, till, and clay bottom. Multiple traces obtained in some areas were correlated with specific clay strata. The effects of rough water and of variation of signal strength are illustrated, and reflections from objects in the water, probably fish, localized in relation to the thermocline, are noted.

DEEP-WATER SEDIMENTS OF LAKE MICHIGAN

A detailed report on this subject is being prepared for publication in the Journal of Sedimentary Petrology. When reprints are available, they will be distributed as Supplement No. 2 of the present report. An abstract of the subject follows.

Abstract

A brief summary of the geologic history of the lake basin is given, and the present environment of sedimentation is described. In the central part of the Lake Michigan basin the glacial to present sequence of sediments is as follows: red till, red gritty clay, red varved clay, red clay, gray clay. Within the red clay there occurs a blue clay zone, and, in depths less 350 feet, a sandy zone recording a time of low water.

The red and the gray clays are similar in their content of quartz, clay minerals (illite is dominant, kaolinite is present), calcite, dolomite, and siderite. The red clay contains hematite. The darker zones of the gray clay, when first analyzed, contain no hematite, but they give a slight exothermic reaction which may represent oxidation of sulfur in ferrous sulfide. After exposure to air the darker zones of the gray clay fade, and then analysis shows the presence of hematite.

The characteristics of these deep-water clays are interpreted as a possible record of changing limnological conditions, as follows: the red clay may have been deposited during a period when no marked thermal stratification of the water existed, and an oxidizing condition prevailed at the bottom. The beginning of gray clay deposition may have coincided with the development of a marked thermal stratification (which exists at

the present time), and it thus may record the development of a reducing environment at the bottom. The interpretation is supported by a study of the ostracode faunas of the sediment, made by Mr. Frank L. Staplin.

If the above interpretation is correct, no marked thermal stratification existed in the Michigan basin from Mankato glacial time until late in the lake history, or until some time between the post-Algonquin low stage (Lake Chippewa) and the Nipissing stage.

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